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Recommended Plan for a Comprehensive Solution of the Polynuclear Aromatic Hydrocarbon Contamination Problem in the St. Louis Park Area

Volume IV
Appendices H - L

ERT
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DEFINITION OF TERMS

Bog	The land immediately south and adjacent to the plant site that received runoff and waste water from the plant site. The bog is bounded by Walker Street to the north, on the east by the route of Louisiana Avenue, on the south by Lake Street and on the west by former railroad embankments. The bog is shown in Figure 2-1.
Benzene Extractable Hydrocarbons	The weight of organic material, per unit volume or mass, obtained on extracting a water or soil sample with benzene. Hydrocarbon in this definition is not meant to be restrictive to material containing carbon and hydrogen, but rather is meant to include all organic material so extracted.
Contaminants	PAH and related compounds that are present in soil or ground water at levels that are clearly above expected background levels for an urban area in the affected media.
Contaminated	Soil or ground water that contains concentrations of PAH and related compounds which are clearly above expected background levels of these compounds for an urban area in the affected media.
Heterocyclic PAH	PAH chemicals with one or more aromatic carbon atoms replaced by nitrogen, oxygen, or sulfur atoms. Unless otherwise stated, alkyl substituted heterocylic PAH are also included by this term.
Hetero-Substituted PAH	PAH chemicals with one or more heteroatomic functional substituted groups attached to the aromatic rings. For the purposes of this term, such functional groups include amines, cyanides, mercaptans, thiols, ketones, ethers, carboxylic acids, alkyl groups, etc. but specifically exclude hydroxyl groups (i.e., phenols).

Modeling Area	An area of 22 miles east-west and 16 miles north-south which is approximately centered on the site area and was modeled for ground-water flow hydraulics as part of this study. The modeling area is defined by the border of the upper map in Figure 2-1.
PAH and Related Compounds	PAH (as defined above) plus related aromatic chemicals that are often associated with PAH in coal tar, soot, petroleum distillates and similar materials. These related aromatic chemicals are by definition limited to heterocyclic PAH, heterosubstituted PAH and phenols (defined elsewhere).
Phenolics	Chemicals measured by standard colorimetric tests for phenols, the current standard test being the 4-aminoantipyrene method. Colorimetric tests typically measure one-ring phenols (phenol and ortho-and meta-substituted phenols and possibly certain para-substituted phenols), and possibly two ring or larger phenols.
Phenols	Chemicals consisting of one or more fused aromatic rings containing carbon and hydrogen with one or more hydroxyl (-OH) groups attached to the ring. Unless otherwise stated, alkyl substituted phenolics are also included by this term.
Plant Site	The land that was formerly the site of the Reilly Tar & Chemical Corporation's creosote wood preserving and coal tar refinery plant. The plant site is bounded on the north by West 32nd street, on the east by Gorham Avenue, Second Street Northwest and Republic Avenue, on the south by Walker Street, and on the West by Pennsylvania Avenue and Oak Hill Park. The plant site is shown in Figure 2-1.

Polynuclear Aromatic Hydrocarbons (PAH)	Chemicals consisting of carbon and hydrogen and containing two or more fused aromatic rings, with each ring consisting of five or six carbon atoms. Unless otherwise stated, alkyl-substituted PAH are also included by this term.
Site	The plant site and bog area together.
Site Area	An area extending approximately 8500 feet east-west and 6000 feet north-south in which the site occupies the northwest corner. The site area is defined by the border of the lower map appearing in Figure 2-1.
St. Louis Park Area	Areas of St. Louis Park and neighboring communities that have been affected by ground water contamination by PAH and related compounds.
St. Louis Park Problem	The overall problems in the St. Louis Park Area related to the contamination of soil and ground water by PAH and related compounds, including in particular the presence of contaminated soil and ground water in the former RT&CC plant site and adjacent bog, the presence of contamination in confined bedrock aquifers underlying the St. Louis Park area, and the present water supply shortage faced by the Cities of St. Louis Park and Hopkins as a result of municipal supply well closures.

DEFINITION OF TRACE CONCENTRATION UNITS

This report makes frequent use of units for expressing trace concentrations. The units used in this report are defined in the table below. In order to avoid misunderstandings over real or suspected typographic errors, an effort has been made to write out all of the units used in this report. Abbreviations are therefore presented below for comparison with other data and reports.

Dimensionless Concentration	Concentration in Water	Concentration in Soil or Other Solid
Parts per million (ppm)	Milligrams per liter (mg/l)	Milligrams per kilogram (mg/kg)
Parts per billion (ppb)	Micrograms per liter ug/l	Micrograms per kilogram (ug/kg)
Parts per trillion (ppt)	Nanograms per liter ng/l	Nanograms per kilogram (ng/kg)

In order to provide a better understanding for the magnitude of these trace concentration units, the following table presents equivalent quantities in more familiar measures of volume, length and time.

Fractional Expression	Volume Equivalent	Length Equivalent	Time Equivalent
1 part per million	1 drop in 26.4 gallons	1 inch in 15.8 miles	1 second in 11.6 days
1 part per billion	1 drop in 26,400 gallons (volume of a typical railroad tank car)	1 inch in 15,800 miles (almost two-thirds of the distance around the earth)	1 second in 31.7 years
1 part per trillon	1 drop in 26.4 million gallons (volume of a 10 acre lake that is 8 feet deep)	1 inch in 15.8 million miles (66 times the distance from the earth to the moon)	1 second in 317 centuries (3 times more distant than the last Ice Age)

APPENDIX H

IMPACTS OF PAH ON NONPOTABLE USE OF GROUND WATER IN THE AFFECTED AREAS

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H1. INTRODUCTION

This appendix assesses the potential impacts of using ground water from the Prairie du Chien-Jordan and Middle Drift aquifers for a variety of non-drinking purposes. This assessment includes using the ground water to water lawns and gardens, to process foods, to bottle soft drinks, and to use in cooling towers and boilers. In each analysis performed, a set of assumptions was developed which translated into an analysis exhibiting worst case conditions. For example, in using Middle Drift water the concentration of PAH was assumed to range from 1000 to 5000 micrograms per liter, a factor 10 greater than available data for wells open to this aquifer indicate. This study also assumed that all PAH in ground water used to water gardens, and in particular lettuce which would show high PAH adsorptive capacity, would be totally adsorbed into the lettuce leaves. Again, this is a worst case analysis in that total adsorption is unlikely. In general, the calculations performed assumed worst case conditions, thus the quantifier of PAH that humans may be exposed to by those various non-drinking paths are conservative.

Human exposure routes included in this assessment were inhalation and ingestion. No literature data are available on the inhalation of noncarcinogenic PAH; however, there is no reason to believe that inhalation exposure is more important than ingestion. Based on available literature, ingestion is considered to be the major pathway for PAH exposure.

H2. PAH CONTAMINATION EFFECTS ON IRRIGATION AND LAWN WATERING

A number of private wells have been identified in St. Louis Park although the community is supplied by a public water system. Most of these wells are not used although some are serviceable and could be used for watering lawns and gardens. This section evaluates potential impacts related to the use of private wells as a source of irrigation waters.

Private wells open to the Drift-Platteville in the immediate downgradient vicinity of the site represent the most significant concern due to the concentrations of PAH and related compounds that have been identified in this area. As described in Appendix B, the concentrations of PAH vary widely over short distances in the immediate vicinity of the site. For purposes of this evaluation, the concentrations of total PAH in the Drift-Platteville are assumed to range from 1000 to 5000 micrograms per liter. This range is considered conservative as the available data indicate that most wells screened in the Drift-Platteville have total PAH concentrations less than 100 micrograms per liter with the exception of piezometer P14, and wells W6 and W13.

Limited data are available concerning the impact of PAH on vegetation. An extensive literature review was conducted by Santodonato et. al. (1979) to evaluate potential sources of PAH present in agricultural crop foods. The authors note that most research indicates that the principal mechanism of PAH uptake is by adsorption rather than absorption. In other words, PAH will accumulate on the surface of roots, leaves etc., however, very little PAH will be translocated from the roots to the shoots. Thus the concentration of PAH present in the roots of crops grown in PAH contaminated soil is expected to be higher than the concentration in the above ground parts. The authors note, however, that the reverse can be true in areas with high concentrations of PAH present in atmospheric dusts. Furthermore, it is possible that irrigation with contaminated water could result in contamination of the above ground parts of food crops. The authors note that only about 10% of the externally deposited benzo(a)pyrene on lettuce, leaks, kale, spinach and tomatoes was removed by cold water washing.

There are no data to indicate at what concentrations PAH in the soil may be phytotoxic. Vegetation has been successfully established at land treatment facilities which had oil concentrations in the soil greater than 2%. Much of this oil was in the form of PAH (Weldon 1980). High concentrations of PAH in the soil, therefore, do not appear to inhibit vegetative growth.

The most significant concern associated with the use of contaminated groundwater for watering lawns and gardens is the potential adsorption of PAH on garden produce and the subsequent human consumption of the produce.

Table H2-1 presents the average monthly water budget in Minneapolis, Minnesota for the months of May through September. The average water deficit during the growing season is approximately 5.7 inches (14.5 cm). Under average climatic conditions, therefore, an individual might apply 5.7 inches of water (3.6 gallons per square foot or 145 liter per square meter) to his garden during a growing season.

A worst case scenario was developed to evaluate potential impacts of utilizing the contaminated Drift-Platteville ground water for watering gardens. Under this scenario it is assumed that all PAH which is present in the water which comes in contact with the vegetative parts of the garden produce for a period of several hours or more will be adsorbed on the vegetative parts. Lettuce is used in the scenario as most of the above ground vegetative portion (which would be exposed to the applied water) is consumed. A water application rate of 12 inches (7.5 gallons per square foot or 305 liters per square meter) over the growing season is assumed to account for over watering and drought conditions.

Vegetation, like glass, has a nonwetting surface (i.e., water running over the surface will immediately run off). A small portion of the water, however, will be retained on the surface as a series of discrete droplets due to surface tension effects. The potential exists, therefore, that some portion of the PAH present in the retained droplets will be adsorbed onto the vegetative area.

TABLE H2-1

AVERAGE MONTHLY WATER BUDGET FOR MINNEAPOLIS

Month	Precipitation (inches)	Evapotranspiration[a] (inches)	Water Deficit[b] (inches)
May	3.19	3.27	-0.08
June	4.00	4.79	-0.79
July	3.27	5.71	-2.44
August	3.18	4.93	-1.75
September	2.43	3.06	-0.63
Total	16.07	21.76	-5.69

a - calculated by the Thornthwaithe method

b - net water deficit: Precipitation - Evaportanspiration

c - NOAA 1978

The quantity of water which will remain on the vegetation after watering a garden can be estimated based on the exposed surface area of the vegetation and empirical data relating to the fluid dynamics of nonwetting surfaces. A completely saturated nonwetting surface will have a film of water which quickly runs off the surface leaving discrete droplets behind. Experience indicates that the thickness of this film is approximately 0.01 centimeters before it breaks up. Hence, the maximum volume of water which could remain on nonwetting surface would be the thickness of the film times the surface area of the nonwetting surface. Although this calculation would clearly over estimate the quantity of water remaining on the surface, it provides a useful worst case volume for comparison purposes.

Certain types of lettuce have a leaf area of 75 square centimeters (Naylor and Loehr, 1982). The volume of water remaining on one lettuce leaf after a watering would be:

Thickness of film x surface area =
0.01 centimeters x 75 square centimeters = 0.75 cubic centimeters

Between each watering, the droplets evaporate and are replaced by new droplets on the subsequent watering. The cumulative amount of droplets which the leaf was exposed to, if the garden was watered weekly for 3 months is:

.75 cubic centimeters x 12 = 9 cubic centimeters =
.009 liters per lettuce leaf

If all the PAH contained in this volume of water was retained on the lettuce leaf, the resulting mass of PAH adsorbed to the lettuce leaf would be a function of the concentration of PAH in the applied water. For our Middle Drift example of 1000 to 5000 micrograms per liter, the resulting mass is 9 to 45 micrograms per leaf.

For the Prairie du Chien example of 10 to 500 micrograms per liter, the resulting PAH mass is 0.09 to 3.6 micrograms per leaf.

The acceptable daily PAH intake is 750 to 980 micrograms per day (Appendix I). Under these conditions, the acceptable lettuce leaf intake (assuming no other sources of PAH) would be 17 to 109 lettuce leaves per day for the Middle Drift case and 208 to 10,889 lettuce leaves for the Prairie du Chien case.

The assumptions used in these examples are purposely conservative. Clearly not all PAH in the water film would adsorb on the lettuce leaf. Photo oxidation should result in a significant removal of the PAH which had adsorbed on the leaf. Furthermore, a lettuce which had grown for as long as 90 days would not be particularly palatable. Finally, the diet of a gardener would include lettuce leaves from the garden for a very short period of time each year.

The above example illustrates that the quality of the Prairie du Chien is acceptable for gardening purposes. The quality of the Middle Drift most likely is also. At present, however, the safety factor involved is not great enough to recommend the uncontrolled use of the Middle Drift on produce which is consumed raw.

Application of contaminated groundwater to lawns may result in an increase in PAH concentrations in the soil. Assuming a soil bulk density of 1.3 grams per cubic centimeter and that all PAH that are applied in the irrigation water are retained in the top 6 inches (15 centimeters) of soil, this would result in an annual increase of 1.6-7.8 parts per million of total PAH in the surface six inches of soil at an application rate of 12 inches/year for the Middle Drift case. This increase should not affect the growth of lawn cover. Accumulation of PAH in the soil may continue in subsequent years. A significant portion of the applied PAH should degrade however. The available data suggest that the use of the contaminated ground water is acceptable for watering lawns.

Based on conservative assumptions, it is not appropriate to use the contaminated Drift ground water for watering vegetable gardens. This recommendation does not imply that limited use of the contaminated ground water on gardens represents a health risk. Rather, the recommendation is based on the assumption that the public should be aware that the use of the contaminated ground water on their gardens may result in higher amounts of PAH in their diet than the

reported average daily PAH exposure amounts from food. Since all the potentially impacted residences are served by a public water supply, the public has a clear choice in terms of the water quality they use in their gardens.

H3. PAH CONTAMINATION EFFECTS ON FOOD PROCESSING, DAIRY PRODUCTS, AND SOFT DRINK BOTTLING

Water is used for a variety of purposes in food processing including: boiler feed, cooling, washing, flushing, processing, and other general purposes. The water used for washing, flushing, processing, and other general uses must be generally of potable quality. Similarly water used in soft drink bottling must be of potable quality. Water requirements for dairy products include wash water and cooling water. The boiler feed and cooling water requirements are similar to other industries requirements and are addressed in Sections H4 and H6.

Although it is not clear that food processors, dairies, or bottlers use Prairie du Chien or Middle Drift water for direct contact processing uses, the following analysis has been completed to describe potential effects. The present information on pumping rates for food processing and bottling indicates a small demand. This small demand may indicate the water is used for needs other than direct contact or processing.

The effects of total PAH concentration in the Middle Drift and Prairie du Chien aquifers have been evaluated using the water requirements in Table H3-1.

Human Exposure from Food Processing

The following assumptions and information were used to assess impacts in food processing.

- Middle Drift PAH concentrations are 1,000 to 5,000 micrograms per liter,
- Prairie du Chien PAH concentrations are 10 to 400 micrograms per liter,
- 100% of PAH in water will be adsorbed,
- Water Requirements (see Table H3-1) are 0.8 to 9.0 gallons per pound,

TABLE H3-1

WATER REQUIREMENTS FOR CANNERIES AND DAIRIES*

	1000 Gallons Per Ton	Gallons Per Pound
Canneries**		
apples	2.4	1.2
apricots	5.6	2.8
asparagus	8.5	4.3
dry beans	8.8	4.4
lima beans	7.7	3.8
snap beans	4.2	2.1
beets	2.7	1.4
broccoli	9.2	4.6
brussels sprouts	8.2	4.1
berries	3.5	1.8
carrots	3.3	1.7
cauliflower	17	8.5
cherries	3.9	2.0
citrus	3.0	1.5
corn	1.8	0.9
grapes	1.5	0.8
mushrooms	7.8	3.9
olives	8.1	4.1
onions	5.5	2.8
peaches	3.0	1.5
pears	3.6	1.8
peas	5.4	2.7
peppers	4.6	2.3
pickles	3.5	1.8
pimentos	6.9	3.5
pineapples	2.7	1.4
plums	2.3	1.2
potato chips	1.6	0.8

TABLE H3-1 (Cont.)

	1000 Gallons Per Ton	Gallons Per Pound
potatoes, sweet	2.2	1.1
potatoes, white	3.6	1.8
pumpkin	2.9	1.5
sauerkraut	0.9	0.5
spinach	8.8	4.4
squash	6.0	3.0
tomatoes, peeled	2.2	1.1
tomatoes, product	1.6	0.8
turnips	7.3	3.7

Dairies and Milk Products**	Gallons per 100 Pounds	Gallons per Pound
receiving station	18	0.2
bottling works	25	0.3
cheese factory	20	0.2
creamery	11	0.1
condensery	15	0.2
dry milk factory	15	0.2
general dairy	34	0.3

*Carawan 1979

**Total indirect and direct contact water use

- 50% of the water usage is for processing and washing (40 - 100% reported, Carawan 1979), and
- Human consumption of canned fruit and vegetables is 8 ounces per day.

Middle Drift Effects:

(1000 - 5000 micrograms per liter) x (0.8 - 9.0 gallon per pound) x (0.5 pound per day) x (100%) x (50%) x (3.785 liter per gallon) = 760 - 43,000 micrograms per day

Prairie du Chien Effects:

(10 - 400 micrograms per liter) x (0.8 - 9.0 gallons per pound) x (0.5 pound per day) x (100%) x (50%) x (3.785 liters per gallon) = 7.6 - 3,400 micrograms per day

Human Exposure from Dairy Products

The water requirements for the dairy products are presented in Table H3-1. The assumptions and information used in evaluating impacts include:

- Middle Drift PAH concentrations are 1000 to 5000 micrograms per liter,
- Prairie du Chien PAH concentrations are 10 to 400 micrograms per liter,
- 20% of the water usage is for direct contact related uses
- Human consumption of dairy products total 1 pound per day, and
- Water requirements (see Table H3-1) are 0.3 gallons per pound.

Middle Drift Effects:

(1000 - 5000 micrograms per liter) x (0.3 gallons per pound) x (1 pound per day) x (20%) x (3.785 liters per gallon) = 230 - 1,100 micrograms per day

Prairie du Chien Effects:

(10 - 400 micrograms per liter) x (0.3 gallon per pound) x
(1 pounds per day) x (20%) x (3.785 liters per gallon)
= 2.3 - 91 micrograms per day

Human Exposure from Bottling Plants

Over 90 percent of the water used in soft drink bottling results in the final product. This water therefore should equal drinking water quality.

The preceeding quantities are generally higher than the average daily intake from water (0.027 micrograms per day) and food (1.6 to 16 micrograms per day) presented by EPA (1980) (see Appendix I). The acceptable daily intake of noncarcinogenic PAH presented in Appendix I is expected to range from 750 to 980 micrograms per day.

There are three known possible users of Middle Drift or Prairie du Chien water for food processing, bottling or dairies (MDNR 1981). They are:

Norris Creameries, Richfield
Lyon Food Products, Minneapolis
7-UP USA, Inc., Edina

None of the above are expected to be within the area of contamination, although the present information does not include the exact well location, pumping rate, or aquifer used. There also may be other users which have not been identified to date which could be affected.

Although existing food processing facilities may not presently use the Middle Drift or Prairie du Chien water in direct contact food processing, it is recommended that they not be used for washing and processing of food. Food processing and dairy facilities may nonetheless use the water for boiler feed or cooling as discussed in the following sections.

H4. BOILER FEED WATER EFFECTS

The primary concern in boiler feed water is scale and sludge deposits from the use of the water. There is no expected direct human exposure resulting from the use of water as boiler feed. The principal scale and sludge forming agents are calcium carbonate, magnesium hydroxide, calcium sulfate and silica. The limiting factors for the use of water for steam generation is the available pressure at the outlet. Table H4-1 presents the limits for boiler water concentration as they relate to steam pressure which is a major concern for boiler feed water. The PAH concentrations for the Middle drift (1 to 5 milligrams per liter) and the Prairie du Chien (0.01 to 0.1 milligrams per liter) will not significantly affect the solids deposition or pressure losses in comparison to the total dissolved solids concentration in the Drift (600 milligrams per liter) and in the Prairie du Chien (300 milligrams per liter).

TABLE H4-1

LIMITS FOR BOILER WATER CONCENTRATIONS[a]

Pressure at Outlet (pounds per square inch)	Total Solids (milligrams per liter)	Total Alkalinity (milligrams per liter)	Suspended Solids (milligrams per liter)
0-300	3500	700	300
301-450	3000	600	250
451-600	2500	500	150
601-750	2000	400	100
751-900	1500	300	60
901-1000	1250	250	40
1001-1500	1000	200	20
1501-2000	750	150	10
2001 and higher	500	100	5

[a]Nordell 1961

H5. PAH CONTAMINATION EFFECTS ON WATER USE FOR AIR CONDITIONING

Air conditioning units use water for both cooling and "conditioning" (removing airborne contaminants and humidifying) air. This often requires direct contact of the water and air. Popular air conditioning systems often include spraying the water as the air passes through the air conditioning system prior to its recirculation. If the water used in the system is contaminanted with PAH, the "conditioned" air could contain volatilized PAH and result in human intake of PAH.

The available information on potential users of contaminated water for air conditioning is presented in Table H5-1. This table reflects the extent of the available information on present users.

The effects of using contaminated water for air conditioning can be assessed by assuming the air is 100% saturated with contaminated water at 77°F (either Middle Drift or Prairie du Chien water). The resultant daily intake (assuming 8 hours exposure) can be evaluated as follows:

Middle Drift:

$$\left(\frac{0.020 \text{ pounds of water (saturation)}}{\text{pounds of air}}\right) \times \frac{(0.0754 \text{ pounds of air})}{\text{cubic foot of air}}$$

$$\times \left(\frac{19 \text{ cubic meters}}{\text{day}}\right)^{*} \times \left(\frac{35.3 \text{ cubic feet}}{\text{cubic meter}}\right) \times \left(\frac{8 \text{ hour}}{24 \text{ hour}}\right)$$

$$\times \left(\frac{454 \text{ grams}}{\text{pound}}\right) \left(\frac{1 \text{ liter water}}{1000 \text{ grams}}\right) \times \left(\frac{1000 - 5000 \text{ micrograms}}{\text{liter}}\right)$$

$$= 150 - 770 \text{ micrograms per day of Total PAH}$$

TABLE H5-1

POSSIBLE USERS OF PAH CONTAMINATED WATER

IN AIR CONDITIONING[a]

Use Type	Permit No.	Permit Holder	Reported Pumping Rate (million gallons per year) 1978	1979	1980
Air Conditioning or Power Generation	610378	Product Design & Engineering	69.08	64.38	6.5
Power Generation or Non-Metallic Products	630319	Minnesota Rubber Company	89.95	69.51	5.1
Power Generation or Non-Metallic Products	660906	McCourtney's Plastics, Inc.	130.7	124.2	1.5
Air Conditioning	756268	United Properties or Well #1	113.9	109.6	6.3
		Southdale Medical Well #2	-	-	2.0
Air Conditioning or Industrial	756162	Red Owl Stores	89.58	86.58	6.5

[a]MDNR 1982

Prairie du Chien:

$$\left(\frac{0.020 \text{ pounds of water}}{\text{pounds of air saturation}}\right) \times \left(\frac{0.0754 \text{ pounds of air}}{\text{cubic feet}}\right) \times \left(\frac{19 \text{ cubic meters}}{\text{day}}\right)^{*}$$

$$\times \left(\frac{35.3 \text{ cubic feet}}{\text{cubic meter}}\right) \times \left(\frac{8 \text{ hour}}{24 \text{ hour}}\right) \times \left(\frac{454 \text{ grams}}{\text{pound}}\right)$$

$$\left(\frac{1 \text{ liter water}}{1000 \text{ grams}}\right) \times \left(\frac{10 - 400 \text{ micrograms}}{\text{liter}}\right) = 1.5 - 61 \text{ micrograms per day of Total PAH}$$

The intake expected from eight hours of exposure in air conditioning using contaminated water is 1 to 3 orders of magnitude higher than typical air exposure. The estimated typical air exposure is 0.21 μg PAH/day per person (see Appendix I). However, the exposure is less than or within the range of acceptable daily intake (see Appendix I).

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*Typical adult breathing rate (Santodonato, et al. 1981).

H6. COOLING TOWER EFFECTS

There may be small cooling tower units which use private wells screened to the Prairie du Chien or Middle Drift aquifers. The effect of using this water has been evaluated to estimate the potential human intake of PAH. The following assumptions have been made in the analysis:

- Assume air is saturated at 160°F;
- Drift = 1 gram of drift per 1 cubic meter of air coming out of the the tower; and
- Inhalation rate is 19 cubic meters per day

Volatilization Effects at Tower:

Middle drift:

$$\left(\frac{0.01294 \text{ pounds water}}{\text{cubic feet air}}\right) \times \left(\frac{19 \text{ cubic meters}}{\text{day}}\right) \times \left(\frac{35.3 \text{ cubic feet}}{\text{cubic meter}}\right)$$

$$\left(\frac{454 \text{ grams}}{\text{pound}}\right) \times \left(\frac{1 \text{ liter water}}{1000 \text{ grams}}\right) \times \left(\frac{1000\text{-}500 \text{ micrograms of PAH}}{\text{liter}}\right)$$

= 3900-19,700 micrograms per day

Prairie du Chien:

$$\left(\frac{0.01294 \text{ pounds water}}{\text{cubic foot air}}\right) \times \left(\frac{19 \text{ cubic meters}}{\text{day}}\right)$$

$$\times \left(\frac{35.3 \text{ cubic feet}}{\text{cubic meter}}\right) \times \left(\frac{454 \text{ grams}}{\text{pound}}\right)$$

$$\times \left(\frac{1 \text{ liter water}}{1000 \text{ grams}}\right) \times \left(\frac{10\text{-}400 \text{ micrograms of PAH}}{\text{liter}}\right)$$

= 39 - 1580 micrograms per day

Drift Effects at Tower:

Middle Drift:

$$\frac{1 \text{ gram drift}}{\text{a cubic meter air coming out of tower}} \times \left(\frac{19 \text{ cubic meter air}}{\text{day}}\right)$$

$$\times \left(\frac{1000\text{-}5000 \text{ micrograms}}{\text{liter}}\right) \left(\frac{\text{liter}}{10^3 \text{ grams}}\right) = 19\text{-}95 \text{ micrograms per day}$$

Prairie du Chien:

$$\frac{1 \text{ gram drift}}{\text{1 cubic meter air coming out of tower}} \times \left(\frac{19 \text{ cubic meter air}}{\text{day}}\right)$$

$$\times \left(\frac{10\text{-}400 \text{ micrograms}}{\text{meter}}\right) \left(\frac{1 \text{ liter}}{10^3 \text{ grams}}\right) = 0.19 - 7.6 \text{ micrograms per day}$$

The maximum expected human exposure from cooling towers (i.e., inhalation of air containing PAH) is based on combined vapor and drift PAH concentrations, with 8 hours of exposure and a dilution of 100. The maximum expected human exposure is presented in Table H6-1. The possible exposure is higher than typical air exposure but is substantially less than the acceptable daily intake (see Appendix I).

TABLE H6-1

POSSIBLE HUMAN EXPOSURE FROM COOLING TOWERS USING PAH CONTAMINATED WATER

	Concentration at the Tower (micrograms per cubic meter)	Concentration at Ground Level (micrograms per cubic meter)	Human Exposure (8 Hours) (micrograms per day)
Middle Drift	210-1040	2.1-10.4	13-66
Prairie du Chien	2-83	0.02-0.8	0.1-5.1

H7. CONCLUSIONS

The preceding sections have presented conservative (worst case) assumptions to assess the maximum impact of the contaminated water or industrial and private uses (excluding potable uses). Table H7-1 presents a summary of expected exposure levels.

The human exposure considered includes both inhalation and ingestion exposure. Although no inhalation studies have been performed to date on noncarcinogenic PAH there is no reason to expect inhalation will have an increased exposure effect (Santodonato 1983). In evaluating carcinogenic effects of PAH, ingestion is considered to be the major pathway of human exposure (Santodonato 1981). Based on the comparison of possible human exposure and acceptable daily intake of noncarcinogenic PAH it may be necessary to prohibit the use of contaminated ground water for food processing.

TABLE H7-1

POSSIBLE HUMAN EXPOSURE FROM NON-POTABLE USE OF PAH CONTAMINATED GROUNDWATER

	Middle Drift (micrograms per day)	Prairie du Chien (micrograms per day)
Gardening	< 500	< 50
Lawn Watering	No Measurable Exposure	No Measurable Exposure
Food Processing	780-43,000	7.6-3400
Dairy Products	230-1,100	2.3-91
Direct Contact Air Conditioning	150-760	1.5-61
Cooling Water	13-66	0.1-5.1
Typical Human Intake of Total PAH	1.8-16	1.8-16
Acceptable Daily Intake of Noncarcinogenic	750-980	750-980

H8. REFERENCES

Carawan, R.E. et al. 1979. "Fruit and Vegetable Water and Wastewater Management." Extension special Report No. AM-18E, January.

Environmental Protection Agency 1980. "Water Quality Criteria for Polynuclear Aromatic Hydrocarbons".

Minnesota Department of Natural Resources (MDNR) Division of Waters 1982. Monthly and annual pumpage of industrial and municipal water permit holders in Hennepin County, Minnesota 1979-1981.

National Oceanic and Atmospheric Administration 1978. "Climates of the States" Gales Research Company, Detroit, Michigan.

Naylor, L.M. and R.C. Loehr 1982. "Priority pollutants in municipal sewage sludge", Biocycle, 23, Nov. and Dec.

Nordell 1961. Water Treatment.

Santodonato J., P. Howard, D. Basu, 1979. Multimedia Health Assessment Document for Polycyclic Organic Matter", prepared for Environmental Protection Agency, Health Effects Research Laboratory, October.

Santodonato, J., P. Howard, D. Basu 1981. "Health and Ecological Assessment of Polynuclear Aromatic Hydrocarbons", Journal of Environ. Pathol. and Toxicol. Vol.5, 1-364.

Santodonato, J. 1983. Personal Communication with John Craun, ERT, April 14.

Weldon, R. 1980. "Biodegradation of Oily Sludge by Soil Microorganisms". Prepared for the American Petroleum Institute, Washington D.C., April.

APPENDIX I

SCIENTIFIC BASIS FOR RECOMMENDED CRITERIA FOR PAH AND HETEROCYCLIC PAH IN POTABLE WATER WITH REFERENCE TO THE ST. LOUIS PARK, MINNESOTA GROUND-WATER SUPPLY

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I1. INTRODUCTION

It is necessary to establish criteria (concentrations related to specific effects), for polynuclear aromatic hydrocarbons and related compounds in drinking water in order to evaluate and ultimately implement solutions for the St. Louis Park problem. This appendix presents the scientific basis for establishing such criteria for PAH and related compounds which are adequate to protect the public health based on available scientific data. However, value judgements regarding acceptable risks and the relative costs and benefits of different criteria are not presented, since such judgments should be reserved for a public forum.

Three basic factual areas relevant to establishing criteria for PAH and related compounds are considered in this appendix. First, the available toxicologic data on the human health effects of PAH are summarized. Taste and odor (organoleptic) impacts are included among the effects of concern. Second, available data on the occurrence and concentrations of PAH in other drinking water supplies are summarized, both for the untreated and finished waters. Third, exposures of human populations to PAH via all major exposure routes (air, food, and drinking water) are estimated and summarized. Data in these three areas provide the necessary basis for developing PAH criteria based on human impacts, in comparison with other water supply systems, or in comparison with exposures from non-drinking water sources.

There are many hundreds - even thousands - of individual PAH compounds. While toxicologic data are not available for all of these compounds, PAH compounds are usefully distinguished on the basis of their carcinogenicity or lack thereof. A number of specific, individual PAH are potent animal carcinogens and implicated as human carcinogens, but this is not true for all PAH compounds. Most PAH, in fact, are not carcinogenic, in which case their toxic effects are relatively mild. The data and analysis in this appendix, therefore, clearly distinguish between carcinogenic and noncarcinogenic PAH.

The evaluation of human health impacts in this appendix covers PAH and heterocyclic PAH. Polynuclear (or polycyclic) aromatic hydrocarbons (PAH) are defined for the purpose of this appendix as all chemicals consisting solely of carbon and hydrogen that contain two or more fused aromatic rings of five or six carbon atoms, including compounds with one or more alkyl groups attached to the aromatic rings. This definition includes some compounds not included under the normal usage of the term PAH, which generally refers only to compounds containing three or more fused aromatic rings. Heterocyclic PAH are defined as any PAH (as defined above) with one or more aromatic carbon atoms replaced by nitrogen, oxygen, or sulfur atoms.

Human health effects are not evaluated in this appendix for heterosubstituted PAH, that is, PAH compounds with one or more heteroatomic functional groups attached to the rings, such as amines, mercaptans, ketones, carboxylic acids, or hydroxy groups. Heterosubstituted PAH are not addressed because they have not been measured to date in untreated drinking water supply samples in the St. Louis Park area (CH2M Hill 1982, see also Appendices G and K). One-ring phenols are not addressed because water quality criteria have already been established for phenols for protection against adverse health effects or objectionable tastes or odors. Criteria have been established both for various isomeric one-ring phenols (U.S. EPA 1976a, 1980e and f) and for various isomeric chlorinated, one-ring phenols (U.S. EPA 1980g, h, and i), which may result from chlorination of water containing phenols (Burttschell, et al 1959).

I2. CARCINOGENIC ACTIVITY OF POLYCYCLIC AROMATIC HYDROCARBONS

I2.1. Summary of Available Information

In this report, a carcinogenic PAH is considered to be one in which a significant elevation in tumor incidence results from the administration of the compound by any route, and to any species of animal. Such compounds are thus treated for regulatory or public policy purposes as though they are human carcinogens, even though the only evidence may be from animal tests. Certain groups, such as the International Agency for Research on Cancer, consider the evidence for carcinogenicity to be sufficient only if the substance results in an increased tumor incidence in multiple species or strains, or in multiple experiments.

Polycyclic aromatic hydrocarbons (PAH) were the first compounds ever shown to be associated with the development of cancers in animals. To this day, carcinogenic PAH are still distinguished by several unique features: (1) several members of the PAH class, most notably benzo[a]pyrene, 3-methylcholanthrene, and 7, 12-dimethylbenz-[a]anthracene, are among the most potent carcinogens known to exist; (2) tumors can be produced by a single exposure to the carcinogen; (3) they act both at the site of contact (e.g., skin, lungs) to produce tumors, as well as at organs distant to the site of absorption; and (4) their carcinogenic effects have been demonstrated in nearly every tissue and species tested, regardless of the route of administration (for a comprehensive review, see Santodonato, et al. 1981). Among the more potent carcinogenic PAH at least one, benzo[a]pyrene, is ubiquitous in the environment and produces tumors in animals that resemble human carcinomas.

Only a small percentage of all PAH have been evaluated for carcinogenic activity. These are primarily the unsubstituted PAH having fewer than eight condensed rings (Table I2-1). Many of the simple alkylated derivatives of carcinogenic PAH will also demonstrate carcinogenic activity (Table I2-2). Numerous heterocyclic derivatives

TABLE I2-1

CARCINOGENIC ACTIVITY OF

SOME UNSUBSTITUTED POLYCYCLIC AROMATIC HYDROCARBONS[a]

Compound	Activity[b]
Acenaphthylene	-
Anthanthrene	-
Anthracene	-
Benzo[a]naphthacene	-
Benzo[a]pyrene	+
Benzo[a]fluorene	-
Benzo[b]chrysene	-
Benzo[b]fluoranthene	+
Benzo[b]fluorene	-
Benzo[c]chrysene	+
Benzo[c]fluorene	-
Benzo[c]phenanthrene	+
Benzo[e]pyrene	-
Benzo[g]chrysene	-
Benzo[g]chrysene	+
Benzo[ghi]fluoranthene	-
Benzo[ghi]perylene	+
Benzo[j]fluoranthene	+
Benzo[k]fluoranthene	-
Benz[a]anthracene	+
Chrysene	+
Coronene	-
Dibenzo[a,e]pyrene	+
Dibenzo[a,h]pyrene	+
Dibenzo[a,i]pyrene	+
Dibenzo[a,j]naphthacene	-
Dibenzo[a,l]pyrene	+
Dibenzo[b,g]phenanthrene	-
Dibenzo[b,k]chrysene	-
Dibenzo[de,qr]naphthacene	-
Dibenzo[e,l]pyrene	-
Dibenz[a,c]anthracene	+
Dibenz[a,h]anthracene	+
Dibenz[a,j]anthracene	+
Fluoranthene	-
Fluorene	-
Hexacene	-
Indeno[1,2,3-cd]pyrene	+

TABLE I2-1 (Continued)

Compound	Activity[b]
Naphthacene	-
Naphthalene	-
Naphtho[2,3-b]pyrene	+
Pentacene	-
Pentaphene	-
Perylene	-
Phenanthrene	-
Picene	-
Pyrene	-
Tribenzo[aei]pyrene	+
Triphenylene	-

[a]Data from Shear, 1938, 1941; Arcos and Argus, 1974; Dipple, 1976; Santodonato et al., 1981

[b]Symbols: + complete carcinogen by either skin painting, subcutaneous injection, intramuscular injection, intravenous injection, intraperitoneal injection, intratracheal instillation, or oral administration to mammals

- negative in animal bioassay

TABLE I2-2

CARCINOGENIC ACTIVITY OF

SOME SUBSTITUTED POLYCYCLIC AROMATIC HYDROCARBONS[a]

Compound	Activity[b]
Substituted Benz[a]anthracene Derivatives	
1-Methylbenz[a]anthracene	-
2-Methylbenz[a]anthracene	+
3-Methylbenz[a]anthracene	+
4-Methylbenz[a]anthracene	+
5-Methylbenz[a]anthracene	+
6-Methylbenz[a]anthracene	+
7-Methylbenz[a]anthracene	+
8-Methylbenz[a]anthracene	+
9-Methylbenz[a]anthracene	+
10-Methylbenz[a]anthracene	+
11-Methylbenz[a]anthracene	+
12-Methylbenz[a]anthracene	+
7-Ethylbenz[a]anthracene	+
8-Ethylbenz[a]anthracene	+
12-Ethylbenz[a]anthracene	+
4-Hydroxybenz[a]anthracene	-
5-Hydroxybenz[a]anthracene	+
7-Hydroxybenz[a]anthracene	-
11-Hydroxybenz[a]anthracene	-
7-Hydroxymethylbenz[a]anthracene	+
4-Methoxybenz[a]anthracene	-
5-Methoxybenz[a]anthracene	+
7-Methoxybenz[a]anthracene	+
8-Methoxybenz[a]anthracene	+
6,7-Dimethylbenz[a]anthracene	+
6,12-Dimethylbenz[a]anthracene	+
7,8-Dimethylbenz[a]anthracene	+
7,11-Dimethylbenz[a]anthracene	+
7,12-Dimethylbenz[a]anthracene	+
4,5-Dimethylbenz[a]anthracene	+
6,8-Dimethylbenz[a]anthracene	+
8,9-Dimethylbenz[a]anthracene	+
8,12-Dimethylbenz[a]anthracene	+
9,10-Dimethylbenz[a]anthracene	+
9,11-Dimethylbenz[a]anthracene	+
1,7-Dimethylbenz[a]anthracene	-
1,12-Dimethylbenz[a]anthracene	-
2,9-Dimethylbenz[a]anthracene	-
2,10-Dimethylbenz[a]anthracene	-
3,9-Dimethylbenz[a]anthracene	-
3,10-Dimethylbenz[a]anthracene	-
4,7-Dimethylbenz[a]anthracene	-
4,12-Dimethylbenz[a]anthracene	-
5,12-Dimethylbenz[a]anthracene	-
8,11-Dimethylbenz[a]anthracene	-

TABLE I2-2 (Continued)

Compound	Activity[b]
5,7-Dimethoxybenz[a]anthracene	-
2,3,7-Trimethylbenz[a]anthracene	-
2,7,12-Trimethylbenz[a]anthracene	-
4,5,10-Trimethylbenz[a]anthracene	+
4,6,8-Trimethylbenz[a]anthracene	+
4,6,12-Trimethylbenz[a]anthracene	+
4,7,12-Trimethylbenz[a]anthracene	+
4,8,12-Trimethylbenz[a]anthracene	+
4,9,12-Trimethylbenz[a]anthracene	+
4,10,12-Trimethylbenz[a]anthracene	+
5,7,12-Trimethylbenz[a]anthracene	+
6,7,12-Trimethylbenz[a]anthracene	+
6,8,12-Trimethylbenz[a]anthracene	+
7,8,12-Trimethylbenz[a]anthracene	+
7,9,12-Trimethylbenz[a]anthracene	+
7,10,12-Trimethylbenz[a]anthracene	+
7,8,9,12-Tetramethylbenz[a]anthracene	+
7,9,10,12-Tetramethylbenz[a]anthracene	+
6,8-Diethylbenz[a]anthracene	+
7,8-Diethylbenz[a]anthracene	-
7,9-Diethylbenz[a]anthracene	-
8,12-Diethylbenz[a]anthracene	+
7-Methyl-12-ethylbenz[a]anthracene	+
8-Ethyl-7,12-dimethylbenz[a]anthracene	-
4-Hydroxy-7,12-dimethylbenz[a]anthracene	-
5-Hydroxy-7-dimethylbenz[a]anthracene	-
4-Methoxy-7,12-dimethylbenz[a]anthracene	-
Substituted Anthracene Derivatives	
9-Ethylanthracene	-
2-Methylanthracene	-
9-Methylanthracene	-
1,2-Dimethylanthracene	-
1,3-Dimethylanthracene	-
1,4-Dimethylanthracene	-
2,3-Dimethylanthracene	-
9,10-Dimethylanthracene	-
1,8,9-Trimethylanthracene	+
2,3,6,7-Tetramethylanthracene	-
Substituted Phenanthrene Derivatives	
1,9-Dimethylphenanthrene	-
1,2,3,4-Tetramethylphenanthrene	+
1,2,4-Trimethylphenanthrene	+

TABLE I2-2 (Continued)

Compound	Activity[b]
Substituted Chrysene Derivatives	
1-Methylchrysene	-
5-Methylchrysene	+
4-Methylchrysene	+
6-Methylchrysene	+
4,5-Dimethylchrysene	+
5,6-Dimethylchrysene	+
1-Methoxychrysene	-
1-Hydroxychrysene	-
3-Hydroxychrysene	+
4-Hydroxychrysene	-
6-Hydroxychrysene	-
2-Methoxychrysene	-
3-Methoxychrysene	-
4-Methoxychrysene	-
6-Methoxychrysene	-
2,3-Dimethylchrysene	-
5,6-Dimethoxychrysene	-
Substituted Benzo[c]phenanthrene Derivatives	
5-Methylbenzo[c]phenanthrene	+
6-Methylbenzo[c]phenanthrene	+
2-Methylbenzo[c]phenanthrene	+
3-Methylbenzo[c]phenanthrene	+
4-Methylbenzo[c]phenanthrene	+
5-Ethylbenzo[c]phenanthrene	+
2,3-Dimethylbenzo[c]phenanthrene	-
5,8-Dimethylbenzo[c]phenanthrene	-
5,8-Diethylbenzo[c]phenanthrene	-
Substituted Cholanthrene Derivatives	
3-Methylcholanthrene	±
4-Methylcholanthrene	+
5-Methylcholanthrene	+
3-Ethylcholanthrene	+
2,3-Dimethylcholanthrene	+
1,3-Dimethylcholanthrene	+

[a]Data from Shear, 1938, 1941; Arcos and Argus, 1974; Dipple, 1976; Santodonato et al., 1981

[b]Symbols: + complete carcinogen by either skin painting, subcutaneous injection, intramuscular injection, intravenous injection, intraperitoneal injection, intratracheal instillation, or oral administration to mammals
- negative in animal bioassay

of PAH have also demonstrated carcinogenic activity in animals. Tables I2-3 and I2-4 list the known carcinogenic heterocyclic PAH and some of their unsubstituted derivatives, which retain carcinogenic activity, respectively. It is important to note that the compounds listed in Tables I2-1 through I2-4, while reflecting all readily available test data, represent only a small fraction of all PAH and heterocyclic PAH compounds. The relative proportion of carcinogenic and noncarcinogenic compounds reported in these tables is not indicative of all PAH and heterocyclic PAH compounds. In many cases, in fact, selection of compounds for testing is biased towards compounds that are expected to be carcinogenic. This is particularly true for many of the alkalated derivatives reported in Tables I2-2 and I2-4, where the unsubstituted compounds are carcinogenic. In addition, most of the compounds listed in Tables I2-1 through I2-4 have not been detected in water from contaminated municipal supply wells in St. Louis Park. The last of the compounds in these tables were developed irrespective of whether or not they are found in St. Louis Park waters in order to ensure that adequate monitoring procedures are applied (see Appendix J).

The activity of most carcinogenic PAH was established in studies with rats or mice where the compound was administered by dermal application or subcutaneous injection. Large differences in carcinogenic potency can be observed for certain PAH, depending upon the route used to administer the compound, as well as the sex, species, and strain of the test animals. Therefore, the carcinogenic activity of PAH can only be compared when all the compounds were adminstered by the same route and to the same species of animal. Unfortunately, relatively few PAH have been systematically tested under identical experimental conditions. Mouse skin is known to be highly sensitive to the carcinogenic action of PAH, and serves as a convenient screening system for detecting PAH that have carcinogenic potential (Santodonato, et al. 1981). Therefore, PAH which are found to be noncarcinogenic when applied to the skin of mice are almost never subjected to animal bioassay employing other routes of administration. Although the majority of human exposures to PAH occur by ingestion and inhalation, animal studies using these routes of administration are limited to only a few of the carcinogenic PAH. Furthermore, because of their ability to produce tumors after

TABLE I2-3

CARCINOGENIC ACTIVITY OF

SOME UNSUBSTITUTED HETEROCYCLIC COMPOUNDS[a]

Compound	Activity[b]
Acridine	-
10-Azabenzo[a]pyrene	+
Benz[a]acridine	+
Benz[c]acridine	+
Benzo[f]benzo[2,3]thieno[3,2-b]quinoline	+
Benzo[h]benzo[2,3]thieno[3,2-b]quinoline	+
11H-Benzo[a]carbazole	+
7H-Benzo[g]-γ-carboline	+
Benzo[h]naphtho[1,2-f]quinoline	+
7H-Benzo[a]pyrido[3,2-g]carbazole	+
7H-Benzo[c]pyrido[3,2-g]carbazole	+
7H-Benzo[g]pyrido[3,2-a]carbazole	+
13H-Benzo[a]pyrido[3,2-i]carbazole	+
Benzoquinoline	-
Carbazole	-
4,11-Diazabenzo[b,def]chrysene	+
1,12-Diazabenzo[rst]pentaphene	+
Dibenz[a,h]acridine	+
Dibenz[a,j]acridine	+
Dibenz[c,h]acridine	+
Dibenzo[a,h]carbazole	+
7H-Dibenzo[a,g]carbazole	+
13H-Dibenzo[a,i]carbazole	+
7H-Dibenzo[c,g]carbazole	+
Fluoreno[9,9a,1-gh]quinoline	+
Phenanthro[2,1-d]thiazole	+
Pyrido[2,3-a]thieno[2,3-i]carbazole	+
Quinoline	+
Tricycloquinazoline	+

[a]Data from Shear, 1938, 1941; Arcos and Argus, 1974; Dipple, 1976; Santodonato et al., 1981

[b]Symbols: + complete carcinogen by either skin painting, subcutaneous injection, intramuscular injection, intravenous injection, intraperitoneal injection, intratracheal instillation, or oral administration to mammals

- negative in animal bioassay

TABLE I2-4

CARCINOGENIC ACTIVITY OF

SOME SUBSTITUTED BENZACRIDINES[a]

Compound	Activity[b]
Substituted Benz[a]acridine Derivatives	
9-Methylbenz[a]acridine	-
10-Methylbenz[a]acridine	-
12-Methylbenz[a]acridine	-
10-Ethylbenz[a]acridine	-
8,9-Dimethylbenz[a]acridine	-
8,12-Dimethylbenz[a]acridine	+
9,12-Dimethylbenz[a]acridine	+
2,9,12-Trimethylbenz[a]acridine	-
8,9,12-Trimethylbenz[a]acridine	-
8,11,12-Trimethylbenz[a]acridine	-
9,11,12-Trimethylbenz[a]acridine	-
3,8,12-Trimethylbenz[a]acridine	+
8,10,12-Trimethylbenz[a]acridine	+
9,10,12-Trimethylbenz[a]acridine	+
2,8,10,12-Tetramethylbenz[a]acridine	-
3,8,10,12-Tetramethylbenz[a]acridine	-
2,3,8,10,11-Pentamethylbenz[a]acridine	-
2,3,9,10,12-Pentamethylbenz[a]acridine	-
2,3,8,10,11,12-Hexamethylbenz[a]acridine	-
Substituted Benz[c]acridine Derivatives	
7-Methylbenz[c]acridine	+
8-Methylbenz[c]acridine	-
9-Methylbenz[c]acridine	-
10-Methylbenz[c]acridine	-
5,7-Dimethylbenz[c]acridine	-
7,9-Dimethylbenz[c]acridine	+
7,10-Dimethylbenz[c]acridine	+
7,11-Dimethylbenz[c]acridine	+
10,11-Dimethylbenz[c]acridine	-
5,7,11-Trimethylbenz[c]acridine	+
7,8,11-Trimethylbenz[c]acridine	+
7,9,10-Trimethylbenz[c]acridine	+
7,9,11-Trimethylbenz[c]acridine	+
7-Ethyl-9-methylbenz[c]acridine	+
7,8,9,11-Tetramethylbenz[c]acridine	+
7-Methyl-9-ethylbenz[c]acridine	+
7-Methoxy-9-methylbenz[c]acridine	+

[a]Data from Shear, 1938, 1941; Arcos and Argus, 1974; Dipple, 1976; Santodonato et al., 1981

[b]Symbols: + complete carcinogen by either skin painting, subcutaneous injection, intramuscular injection, intravenous injection, intraperitoneal injection, intratracheal instillation, or oral administration to mammals
- negative in animal bioassay

unusually short periods of exposure (often a single dose), very few animal studies are conducted which involve chronic administration of carcinogenic PAH.

The potential carcinogenicity of PAH is dependent on their ability to be converted by metabolism in the body to a specific reactive intermediate, most probably a diol-epoxide. Therefore, the carcinogenic activity of an individual PAH is dependent upon the extent to which these diol-epoxides are formed from the parent hydrocarbon. A theory has emerged which predicts that diol-epoxides in which the oxirane oxygen forms part of a "bay region" (e.g., the 7,8-diol-9,10-epoxide of benzo[a]pyrene) will be more reactive and hence more carcinogenic than diol-epoxides in which the oxirane oxygen is not situated in a "bay region" (Santodonato, et al. 1981). This theory has been confirmed in numerous experiments with PAH, and thus suggests that an analysis of theoretical reactivity (e.g., by molecular-orbital calculations) may be useful in screening untested PAH as potential carcinogens.

Epidemiologic evidence from exposed worker populations has established that human occupational exposure to certain PAH-containing substances is associated with an elevated cancer risk (Redmond, et al. 1979, 1976, 1972; Hammond, et al. 1976; Doll, et al. 1972; Cookson 1924; Haldin-Davis 1935; Lenson 1956). Animal studies with various coal tar derivatives confirm the carcinogenicity of these PAH-containing complex mixtures (Horton et al. 1953; Tye and Stemmer 1967; Kinkead 1973; McConnell and Specht 1973; MacEwen and Vernot 1976; MacEwen, et al. 1976; Wallcave, et al. 1971; Lijinsky, et al. 1957; Boutwell and Bosch 1958; Roe, et al. 1958). There is no conclusive evidence available from community populations, however, to specifically implicate nonoccupational PAH exposure as a risk factor for cancer development in man.

In the environment, man is unlikely to come in contact with only a single PAH, regardless of the route of exposure. Instead, PAH occur as complex mixtures in all environmental media. Despite this fact, relatively little is known concerning the biological interactions which may result when simultaneous exposure to more than one PAH

occurs. In certain cases the effects of multiple PAH exposure are additive, in other cases significant inhibition occurs, and with a few PAH an enhancement of carcinogenesis is observed. It is important to note that true synergism is a rare biological phenomenon, and its relevance to PAH-induced carcinogenesis in man is questionable.

It is well-known that the development of polycyclic hydrocarbon-induced tumors can be altered by: (1) components in the diet, (2) agents which affect the activity of certain enzymes, (3) other coadministered non-carcinogenic or weakly carcinogenic chemicals, or (4) the vehicle used to deliver a carcinogen to experimental animals. These influences can have an important effect on possible threshold levels for tumorigenic response, although the mechanism of such interactive effects are unknown. These factors further complicate the extrapolation of experimental animal data to human situations.

Early work on the inhibition of carcinogenesis was reviewed by Falk, (1964). In addition, they conducted a series of studies to evaluate the carcinogenic action of 3-methylcholanthrene, dibenz[a,h]anthracene, and benzo[a]pyrene in the presence of closely related PAH. Simultaneous administration of dibenz(a,h)anthracene or 3-methylcholanthrene (30 micrograms) with 15 times the molar equivalent of their respective dihydro- or hexahydro-reduction products by subcutaneous injection to male C57 black mice caused either a complete inhibition or dramatic reduction of the normal carcinogenic response. Administration of the dihydro- and hexahydro-derivatives at intervals extending from fourteen days prior to and seven days subsequent to dibenz[a,h]anthracene (60 or 135 ug) injection also caused significant inhibition of tumor development. Injections of the non-carcinogen phenanthrene together with dibenz[a,h]anthracene in molar ratios of 1:24 and 1:48 significantly reduced tumor yield. In simulated environmental studies benzo[a]pyrene was administered to mice together with various non-carcinogenic PAH commonly found in polluted atmospheres. The results demonstrated that in all cases a marked inhibition of carcinogenesis resulted. Neutral fractions (which contained PAH) isolated from a polluted urban atmoshpere produced inhibitory efforts with benzo[a]pyrene.

In one subcutaneous injection study in mice (Pfeiffer 1973, 1977), it was shown that a combination of 10 noncarcinogenic PAH, mixed according to the proportion occurring in automobile exhaust, did not enhance or inhibit the tumorigenic action of two carcinogenic PAH, benzo[a]pyrene and dibenz[a,h]-anthracene. Schmahl et. al. (1977) conducted a similar study in which defined mixtures of 4 carcinogenic PAH and 7 noncarcinogenic PAH were applied to the skin of mice at several dose levels for their entire lifetime. These investigators found no effect on tumor incidence that could be attributed to the presence of noncarcinogenic PAH in the mixture. Therefore, it appears reasonable to evaluate the carcinogenic risk of complex PAH mixtures based on the sum of its individual carcinogenic constituents.

I2.2. Approaches to Risk Assessment for Carcinogenic Polycyclic Aromatic Hydrocarbons

Carcinogenicity is presently the biological endpoint of greatest societal concern in conducting risk assessments on environmental contaminants. Scientifically, the concern for cancer risk focuses on the concept of "threshold". Several reputable scientific bodies have concluded that there is no scientific basis for assuming the existence of a threshold, or no-effect level of exposure, for chemical carcinogens (NAS 1977; Albert, et al. 1977). The existence of no-effect levels for exposures to carcinogens is a matter of considerable uncertainty and scientific debate. If the no-threshold concept is accepted, one must then assume that a finite risk of cancer development is associated with exposure to all carcinogens, no matter how small the dose. In conducting this risk assessment this conservative assumption regarding the non-threshold action of carcinogens has been adopted.

Although the problem of carcinogenic risk is real, it can be very difficult to analyze both qualitatively and quantitatively. The qualitative analysis of carcinogenic potential for a substance involves a critical evaluation of the overall weight-of-evidence derived from human epidemiological studies and bioassays with experimental mammals. For many chemicals, conflicting evidence and

non-interpretable data make the qualitative determination of carcinogenicity very difficult. This is not the case for most carcinogenic PAH, however.

On the other hand, quantitative determination of carcinogenic risk for specific PAH is faced with several obstacles: (1) the available human evidence involves exposures to complex mixtures containing carcinogenic and noncarcinogenic PAH, where the actual doses and causative agent(s) were not defined; (2) the routes of exposure employed in animal studies are generally not representative of human exposures in the environment; and (3) the short duration of carcinogen exposure in most animal studies is not representative of the lifetime duration of exposure to PAH which most humans receive.

The best available evidence for quantitative estimation of carcinogenic risk for PAH comes from animal studies, despite their limitations as indicated above. On the positive side, animal bioassays involve exposure of mammals to defined dose levels under controlled conditions. For several of the specific carcinogenic PAH -- notably benzo[a]pyrene, dibenz[a,h]anthracene, and 3-methylcholanthrene -- relevant bioassay data involving oral exposures are available for risk extrapolation (Neal and Rigdon 1967; Snell and Stewart 1962; Homburger, et al. 1978). From these animal data it is possible to estimate in a quantitative fashion the carcinogenic risk to humans who are similarly exposed via drinking water or the diet.

The extrapolation of animal bioassay data to humans requires the use of a mathematical model to estimate doses which produce response levels that cannot be directly observed. This is necessary because acceptable levels of human cancer risk (on the order of 10^{-5}-10^{-6}) are far below the detection limit of even the most elaborate of experimental studies. At low levels of response which are directly relevant to human risk assessment, but which are not directly observable in animal bioassays, the shape of the dose-response curve is uncertain (Stara et. al., 1980). It is important to recognize that doses associated with measurable responses in animal bioassays are generally about six orders of magnitude greater than extrapolated

doses associated with acceptable levels of risk; thus, it is obvious that no animal study could provide dose-response data that could be used directly for risk assessment. It is assumed, however, as previously discussed, that chemical carcinogens elicit non-threshold responses so that the dose-response curve will reach zero response only at zero dose. Thus, several non-threshold mathematical models have been developed to describe the dose-response relationship for carcinogenic chemicals.

In deriving ambient water quality criteria for PAH, the U.S. Environmental Protection Agency has adopted the non-threshold assumption in using the so-called "one-hit" extrapolation model (Federal Register, 41: 21402, 1976). The basic dose-response model is described by the equation

$$P = 1-\exp[-BD]$$

where P is the probability of developing cancer resulting from a daily dose D of a substance, and B is a constant determined by the data. At very low doses, P is directly proportional to the dose D, and B is the slope of the dose-response line obtained when P is plotted against D. Because the model approximates a straight line through the origin at low doses, it is often referred to as a linear non-threshold dose-response model (Stara, et al. 1980). It is considered to be one of the most conservative extrapolation models available, since it is less likely to underestimate carcinogenic risks at the low doses typical of environmental exposures. The model, as applied in deriving ambient water quality criteria, uses the upper 95% confidence limit of the estimated carcinogenic potency factor to calculate the doses resulting in defined levels of risk. An ambient water quality criterion, derived using the one-hit model, is an estimate of the concentration of a substance in ambient water which would be associated with a specified increased lifetime risk of a 70 kg human developing cancer from drinking 2 liters of contaminated water per day throughout his life and consuming 18.7 grams per day of fish taken from contaminated waters. A specified lifetime risk level of 10^{-5} (generally regarded as a maximum acceptable risk) indicates a probability of one additional case of cancer (but not necessarily a cancer death) for every 100,000 people exposed for their entire lifetime.

The U.S. Environmental Protection Agency has acknowledged that it is not possible to derive a cancer-based ambient water quality criterion for PAH as a class (U.S. EPA 1980a). Furthermore, it has been properly recognized that the presently available data base is inadequate to support the derivation of individual criteria for each of the known carcinogenic and noncarcinogenic PAH. Instead, criteria have been developed for the two carcinogenic PAH (benzo[a]-pyrene and dibenz[a,h]anthracene) that occur in ambient water and for which the available data are adequate for extrapolation to humans. The ambient water quality criterion corresponding to a 10^{-5} lifetime cancer risk level for benzo[a]pyrene is 28 nanograms per liter. This criterion has been applied by the U.S. EPA to all carcinogenic PAH as a class, based on the assumption that in mixtures containing more than one carcinogenic PAH each compound is as potent as benzo[a]pyrene, and thus that the total of all compounds should not exceed the 28 nanograms per liter criterion based on benzo[a]pyrene alone (U.S. EPA 1980a). The corresponding criterion based on the data for dibenz[a,h]anthracene is 43 nanograms per liter. If the contribution to exposure from consumption of contaminated fish was ignored, then the water quality criteria would be increased to 35 nanograms per liter and 54 nanograms per liter for benzo[a]pyrene and dibenz[a,h]anthracene, respectively. It is reasonable in the case of ground water used as a public supply to ignore the uptake of PAH by fish and set a criterion of 35 nanograms per liter for total carcinogenic PAH, using the above approach. Such a criterion is not substantially different from the EPA criterion of 28 nanograms per liter. It is thus reasonable to adopt the latter.

Based on results discussed earlier, the presence of noncarcinogenic PAH in complex environmental mixtures is assumed to neither enhance nor inhibit the activity of its carcinogenic constitutents. This approach to risk assessment for carcinogenic PAH is admittedly a very conservative one. However, it is reasoned that because of the uncertainties associated with high-to-low dose and animal-to-human extrapolation, this approach is justified in light of the serious public health consequences that could result if the risk were underestimated (Stara, et al. 1980).

I3. RISK ASSESSMENT FOR NONCARCINOGENIC POLYCYCLIC AROMATIC HYDROCARBONS

The major difference between risk assessments for carcinogens and noncarcinogens is that in the latter case it is assumed that a threshold exposure level exists, below which no significant adverse effects are produced in healthy populations. The threshold approach, therefore, assumes the existence of a "no observable adverse effect level" (NOAEL), which can often be inferred from appropriately designed animal bioassays. In order to approximate more closely the conditions of human exposure, preference is always given to animal studies involving chronic exposures (by the oral route, if water quality criteria are to be derived) extending over a large portion of the test organism's lifespan (Stara, et al. 1980). Ideally, animal studies will be found which demonstrate dose-related adverse effects as well as no-effect levels of exposure. The biological endpoints measured in determining a NOAEL can be diverse, ranging from gross effects such as death to more subtle changes in biochemical, physiological, or pathological parameters. A NOAEL based on animal bioassay data is transformed into an acceptable daily intake (ADI) for man by dividing the number by an uncertainity factor of 10, 100, or 1000 according to the guidelines given by the National Academy of Sciences (NAS 1977).

For some chemicals, an ADI derived from animal bioassay data may be unacceptable because of effects on humans which are not directly health-related. This situation arises with organoleptic effects, whereby a chemical may impart objectional taste or odor to water (or air) at levels which result in exposures below the calculated ADI. Under these circumstances, it is generally necessary to adopt a more stringent criterion based on the organoleptic properties of the substance.

For the purpose of calculating ADI's for humans, the data base on noncarcinogenic PAH is very poor. This is attributable for the most part to: (1) lack of animal studies employing long-term duration of exposure to PAH; (2) inappropriate route of exposure (i.e., skin

painting, subcutaneous injection) in most animal studies for extrapolation to humans; and (3) lack of chronic animal studies involving exposure to PAH mixtures. These problems were acknowledged in the Environmental Protection Agency's Ambient Water Quality Criteria Documents for PAH (U.S. EPA 1980a), fluoranthene (U.S. EPA 1980b), acenaphthene (U.S. EPA 1980c), and acenaphthylene (U.S. EPA 1980d).

One approach to the derivation of an ADI for noncarcinogenic PAH is by analogy with one or more of the well-studied carcinogenic PAH. This is necessary because long term oral exposure studies have been conducted on only a few carcinogenic PAH. The basic assumption that one must accept in following this approach is that the chronic toxicity of the noncarcinogenic PAH is the same (or similar) as for the carcinogenic PAH, with the exception of tumor formation. This assumption appears to be reasonable, based on long-term skin painting studies and the known acute toxicities of both carcinogenic and noncarcinogenic PAH. If anything, the acute toxicity of carcinogenic PAH appears to be much greater than for the noncarcinogens (Shear 1937, 1941; Haddow, et al. 1937; Hoch-Ligeti 1941; Shubik and Della Porta 1957; Yoshida and Fukunishi 1977). Therefore, using information from a chronic animal bioassay where a NOAEL for non-tumor toxic endpoints was determined should lead to a conservative estimate of the ADI for noncarcinogens. A NOAEL taken from studies on individual PAH must be used in this approach since there are no studies available which provide NOAEL's for PAH-containing mixtures (such as creosote).

A study involving intragastric administration of 3-methylcholanthrene to hamsters (Homburger, et al. 1978) provides an excellent illustration of how the approach can work. 3-Methylcholanthrene is one of the most potent of all the carcinogenic PAH. In this study, 3-methylcholanthrene was administered to groups of female hamsters 3 times per week for 17 weeks at 3 dose levels (0.05, 0.1, and 4 milligrams per dose). The treated animals were weighed weekly and all subjects were autopsied after 70 weeks, when most of the negative control animals had died. Tumor formation and

decreased survival were seen only at the highest exposure level (Table I3-1). At the two lower doses of 3-methylcholanthrene there was no statistically significant increase in tumor incidence, no adverse effect on body weight gain, and no difference in survival curves when compared with untreated control animals. Taking the 0.1 milligram dose of 3-methylcholanthrene tested as a conservative estimate of the NOAEL, a transformed daily dose can be calculated as shown in Table I3-2. This transformed dose of 0.35 milligrams per kilogram per day can be used to derive an ADI for humans by application of an uncertainty factor of 100; as recommended by the National Academy of Sciences (NAS 1977, see page I-44 of this appendix). By this procedure an ADI for the noncarcinogenic action of 3-methylcholanthrene is 3.5 micrograms per kilogram per day, or 245 micrograms per day for a 70 kilogram adult human. Assuming that 2 liters of water are consumed per day (NAS 1977), then the appropriate criterion would be 120 micrograms per liter (assuming no contribution from contaminated fish). This 120 micrograms per liter criterion can subsequently be applied as an acceptable level of contamination in water representing the sum of all noncarcinogenic PAH.

For the sake of comparison, a NOAEL for benzo[a]pyrene can be derived from studies involving dietary administration to mice (Neal and Rigdon 1967). Mice tolerated a diet containing benzo[a]pyrene at 0.01 milligram per gram of food for 110 days (total intake of benzo[a]pyrene was 4.48 milligrams) with no effect on survival or tumor formation (Table I3-3). This level of exposure corresponds to a daily intake of 1.06 milligrams per kilogram per day, or 74.7 milligrams per day for a 70 kilogram adult human. The corresponding water quality criterion based on the above data for benzo[a]pyrene by ingestion with an uncertainty factor of 100 would be 370 micrograms per liter. This value compares favorably with the derived water quality criterion of 120 micrograms per liter based on the data for 3-methylcholanthrene.

It is also important to note that the U.S. Environmental Protection Agency has promulgated a water quality criterion limit for fluoranthene, a noncarcinogenic PAH, based on an estimate of human

TABLE I3-1

BIOASSAY DATA FOR 3-METHYLCHOLANTHRENE

Reference: Homburger et al., 1978

Exposure Route	Species/ Strain	Sex	Dose or Exposure	Duration of Treatment	Duration of Study	Purity of Compound	Vehicle or Physical State	Target Organ	Tumor Type	Tumor Incidence
ig	hamster/ B10 15.16	M	0.05 mg, 3 times/week for a total of 50 doses	17 weeks	70 weeks	NR	0.4 mℓ tricaprylin	breast	carcinoma	0/17
ig	hamster/ B10 15.16	M	4 mg, 3 times/week for a total of 50 doses	17 weeks	70 weeks	NR	0.4 mℓ tricaprylin	breast	carcinoma	11/21[a]
ig	hamster/ B10 15.16	M	0.1 mg, 3 times/week for a total of 50 doses[d]	17 weeks	70 weeks	NR	0.4 mℓ tricaprylin	breast	carcinoma	0/15[b]
ig	hamster/ B10 15.16	M	untreated	NA	70 weeks	NA	NA	breast	carcinoma	0/16[c]
ig	hamster/ B10 15.16	M	0.01 mg, Reserpine 3 times/week for a total of 50 doses	17 weeks	70 weeks	NA	0.2 mℓ tricaprylin	breast	carcinoma	0/20

QUALITY OF EVIDENCE

Strengths of Study: Excellent reporting of data; histopathologic examinations performed; vehicle and untreated control groups included; no breast tumors were found in any of the control animals.

Weakness of Study: Inbred strain of hamster employed may be highly susceptible to mammary tumorigenesis by chemical treatment; limited treatment duration; small numbers of animals treated; no statistical analysis of data.

Overall Adequacy: Adequate

[a] Additional tumors included 3 adenocarcinomas of the colon, 2 lymphomas, and 2 sarcomas (cecum and ovary).

[b] Two lymphomas observed; not significantly elevated in comparison to untreated control

[c] One lymphoma observed

[d] Treatment also included 0.01 mg Reserpine with each dose of 3-methylcholanthrene

NA = Not applicable; NR = Not reported; ig = intragastric

TABLE I3-2

TRANSFORMED DOSES FOR 3-METHYLCHOLANTHRENE BIOASSAY DATA

REFERENCE:	Homburger et al., 1978			
EXPOSURE ROUTE:	intragastric			
SPECIES:	hamster			
STRAIN:	B10 15.16			
SEX:	female			
VEHICLE OR PHYSICAL STATE:	.4 mℓ tricaprylin			
BODY WEIGHT:[a]	0.12 kg			
DURATION OF TREATMENT:	119 days			
DURATION OF STUDY:	490 days			
LIFESPAN OF ANIMAL[a]:	730 days			
TARGET ORGAN:	breast			
TUMOR TYPE:	carcinoma			
EXPERIMENTAL DOSES/ EXPOSURE:	4 mg, 3 times/week	0.4 mg, 3 times/week	0.05 mg, 3 times/week	0.0 mg in tricaprylin, 3 times/week
TRANSFORMED DOSES (mg/kg/day):	14.0	1.4	0.02	0.0
TUMOR INCIDENCE:	11/21	0/15	0/17	0/15

[a]estimated

TABLE I3-3

BIOASSAY DATA FOR BENZO(A)PYRENE BY DIETARY ADMINISTRATION

Reference: Neal and Rigdon, 1967

Exposure Route	Species/ Strain	Sex	Dose	Duration of Treatment	Duration of Study	Purity of Compound	Vehicle or Physical State	Target Organ	Tumor Type	Tumor Incidence
o	mice/ CFW	M/F	1 ppm (0.48 mg total dose)	110 days	140 days	NR	diet	stomach	papillomas/carcinomas	0/25
o	mice/ CFW	M/F	10 ppm (4.48 mg total dose)	110 days	140 days	NR	diet	stomach	papillomas/carcinomas	0/24
o	mice/ CFW	M/F	20 ppm (8.88 mg total dose)	110 days	226 days	NR	diet	stomach	papillomas/carcinomas	5/23
o	mice/ CFW	M/F	30 ppm (13.32 mg total dose)	110 days	143-177 days	NR	diet	stomach	papillomas/carcinomas	0/37
o	mice/ CFW	M/F	40 ppm (17.76 mg total dose)	110 days	143-211 days	NR	diet	stomach	papillomas/carcinomas	1/40
o	mice/ CFW	M/F	45 ppm (19.8 mg total dose)	110 days	141-183 days	NR	diet	stomach	papillomas/carcinomas	4/40
o	mice/ CFW	M/F	50 ppm (21.4-29.4 mg total dose)	107-197 days	124-219 days	NR	diet	stomach	papillomas/carcinomas	24/34
o	mice/ CFW	M/F	100 ppm (39.2-48.8 mg total dose)	98-122 days	118-146 days	NR	diet	stomach	papillomas/carcinomas	19/23
o	mice/ CFW	M/F	250 ppm (70-165 mg total dose)	70-165 days	88-185 days	NR	diet	stomach	papillomas/carcinomas	66/73
NA	mice/ CFW	M/F	0.0 ppm	NA	70-300 days	NA	basal diet only	stomach	papillomas/carcinomas	0/289

QUALITY OF EVIDENCE

Strengths of Study: A broad range of dose levels was tested to determine a minimum carcinogenic dose. A natural route of administration was used.

Weakness of Study: The period of treatment and duration of study were short. The purity of BaP is not stated. No statistics were compiled to compare the incidence of tumors.

Overall Adequacy: Adequate

NA = Not applicable; NR = Not reported; o = oral

toxicity from animal studies (U.S. EPA 1980b). The criterion limit is 42 micrograms per liter and is the only health-related criterion limit for a PAH promulgated by the EPA based on noncarcinogenic effects. This limit for fluoranthene is based on dermal administration to mice and an estimated uptake equivalent to 6 milligrams per kilogram per day, assuming 100 percent absorption by the skin. Applying an uncertainly (safety) factor of 1000, and assuming a typical 70 kilogram weight for an adult human, this converts to an acceptable daily intake (ADI) of 420 micrograms per human per day. By the EPA approach, this converts to a criterion limit of 210 micrograms per liter in order to not exceed the ADI. However, their criterion limit also considers bioconcentration by fish (a factor of 1150) and ingestion of such fish and shellfish (6.5 grams per day). On this basis, a lower limit in ambient water (not drinking water alone) of 42 micrograms per liter was developed and promulgated. The EPA calculation assumes that 79% of the ADI at the limit would be due to eating fish contaminated with the same water that would be consumed directly and thereby contribute the remaining 21%.

It is important to know whether water quality criteria based on toxicity data may be unacceptable because of organoleptic effects. Unfortunately, data are scarce concerning the organoleptic effects of PAH and their naturally-occurring mixtures. A few values have been reported in the Compilation of Odor and Taste Threshold Values Data (ASTM 1978). Coal tar and naphthalene are reported to be detectable by odor in water at levels of 4 micrograms per liter and 6.8 milligrams per liter, respectively. Creosote can be recognized by taste in water at a level of 125 micrograms per liter. The reported organoleptic values for coal tar and for creosote are taken from the Russian literature and should not be accepted without confirmation. Nevertheless, it is possible that in the case of coal tar contamination of water, it may be preferable to adopt a criterion based on organoleptic properties, since the toxicity-based criterion for noncarcinogenic PAH may be slightly above the odor threshold. On the other hand, the PAH profile for wells in St. Louis Park is not typical of coal tar, but rather is more indicative of creosote-derived compounds (see Appendix K).

In addition to the organoleptic data discussed above, the USSR has established criteria for two PAH in "water bodies" based on organoleptic effects (Rakhmanina 1964). These limits are 400 micrograms per liter each for phenanthrene and pyrene, both of which are noncarcinogenic PAH. Finally, citing a range of human organoleptic responses of 22 to 220 micrograms per liter to acenaphthene, the U.S. Environmental Protection Agency has promulgated a water quality criterion limit for acenaphthene of 20 micrograms per liter (U.S. EPA 1980c). In summary, the cited organoleptic effects for PAH encompass the range of 4 to 6800 micrograms per liter. The lowest value is for coal tar, which may not be the appropriate value here, considering the very different mix or profile of PAH in the wells at St. Louis Park.

I4. PAH CONCENTRATIONS IN WATER SUPPLIES*

Even though several members of the PAH class of compounds are among the most potent carcinogens known to exist, relatively little research has been devoted to the determination of PAH concentrations in water supplies. Those studies which have documented PAH concentrations in past years may have underestimated the total PAH loadings in aquatic systems due to the lack of required sensitivity in instrumentation used for analysis or the fact that researchers generally measured only the six PAH compounds recommended by the World Health Organization as a measure of PAH contamination (fluoranthene, benzo[ghi]perylene, benzo[k]fluoranthene, indeno[1,2,3-cd]pyrene, benzo[b]fluoranthene and benzo[a]pyrene) (WHO 1971).

Acknowledging that the total PAH concentrations in water systems may be higher than those actually detected, Table I4-1 presents data for average concentrations of carcinogenic and noncarcinogenic PAH occurring in ground, surface, and finished drinking water supplies on a worldwide basis. As shown in this table, the PAH concentrations found in water supplies are variable, even among water supplies of similar types (e.g., surface waters). Generally the data indicate that raw surface waters contain the highest PAH concentrations and that, in most cases, treated surface water used as drinking water has total average PAH concentrations less than 40 nanograms per liter. However, it should be noted that the average noncarcinogenic PAH concentration occurring in <u>treated</u> surface water from twelve Great Lakes municipalities (Williams, et al. 1982) was comparable to the average noncarcinogenic PAH levels measured in <u>untreated</u> surface waters around the world.

*PAH, in this and the following section, refers to organic compounds which contain two or more aromatic rings, as well as their alkylated derivatives. Thus, the simplest PAH compound using this definition would be napthalene. In some cases, researchers investigating the PAH content of water supplies have included biphenyl, bibenzyl, and stilbene under the classification of PAH compounds, although these do not contain fused aromatic rings, and these will be considered as PAH compounds in specified, documented instances. In this and the following section, PAH does not include nitrogen, sulfur, or oxygen containing heterocyclic compounds. Occasionally, oxygenated PAH compounds will be included in the discussion and will be labeled accordingly.

TABLE I4-1

SUMMARY OF PAH AVERAGE CONCENTRATIONS OCCURRING IN WATER SUPPLIES

(Concentrations in nanograms per liter)

Water Source	Carcinogenic[a]	Noncarcinogenic[a]	Activity Unknown[a]	Total	Highest Total PAH Concentration	Reference[b]
GROUND WATER						
Ground water from 6 main geological formations in Belgium	0.9	2	-	3	4	Quaghebeur and DeWulf (1978)
Ground water from 3 sites in Germany	41	187	-	228	381	Borneff & Kunte (1964)
RAW SURFACE WATER						
Surface water from 9 rivers in United Kingdom	308	224	-	532	2826	Crane et al. (1980)
Surface water from 4 sites in Germany	245	195	-	440	1239	Borneff & Kunte (1964)
Surface water for 2 eastern Ontario municipalities	0	43	17	60	103	Benoit et al. (1979)
Surface water at 3 sites from Thames River	886	387	-	1273	1760	Acheson, et al. (1976)
Surface water at 5 sites from Severn River	24	48	-	72	160	Lewis (1975)
Surface water in U.S. (5 sites)	255	360	-	615	1586	Saxena, et al. (1977)

TABLE I4-1 (Cont'd)

Water Source	Carcinogenic[a]	Noncarcinogenic[a]	Activity Unknown[a]	Total	Highest Total PAH Concentration	Reference[b]
Surface water in U.S. (8 sites)	31	37	-	68	150	Sorrell, et al. (1979)
FINISHED DRINKING WATER						
Finished surface water from 12 Great Lakes municipalities	0	280	30	310	3055	Williams, et al. (1982)
Finished drinking water from 6 eastern Ontario municipalities (e)	0.5	15	3	19	30	Benoit, et al. (1979)
Finished water in U.S. (11 sites)	28	8	-	36	139	Saxena, et al. (1977)
Finished water in U.S. (8 sites (i)	8	21	-	29	150	Sorrell, et al. (1979)
U.S. Tap Water (1 site)	0	29	-	29	29	Alben (1980)

Notes:

(a) Carcinogenic activity of individual PAH compounds determined from the data presented in Tables 12-1 through I2-4.
(b) See Table 12-2 for individual PAH compounds analyzed by each study.

Table I4-2 lists the individual PAH compounds measured by the various studies summarized in Table I4-1. The individual PAH analyzed by the various laboratories that have routinely analyzed ground-water samples from St. Louis Park are also listed. Comparing the number and types of PAH analyzed in St. Louis Park with those analyzed by other studies elsewhere clearly shows that many more compounds have been analyzed for in St. Louis Park than in other water supply systems. This must be recognized in comparing PAH data for St. Louis Park with results of other water supply studies.

From the data in Table I4-3, which were used to determine the average PAH concentrations in drinking waters for the 12 Great Lake municipalities, it is evident that there was high variability in PAH and oxygenated PAH concentrations among the sample sites and between two sampling dates per site. Certain municipal drinking waters, especially Sault Ste. Marie, contained relatively high PAH concentrations. On the August 1980 sampling date, the aggregate PAH and oxygenated-PAH levels in treated water at Sault Ste. Marie exceeded 3 micrograms per liter. In addition, the U.S. EPA has reported that natural waters in the U.S. contain up to 2.0 micrograms per liter of naphthalene, with drinking water supplies containing up to 1.4 micrograms per liter (U.S. EPA 1980j).

The highest concentrations of individual PAH and oxygenated-PAH contained in the finished drinking water from the twelve Great Lakes municipalities are presented in Table I4-4. As can be calculated from these data, if these PAH compounds were contained in a single water sample at their highest concentration, the total PAH and oxygenated-PAH concentrations would be approximately 3.3 micrograms per liter. None of the PAH that contribute to this total, would be categorized as being carcinogenic.

Well SLP15 contains some of the highest PAH concentrations among contaminated municipal supply wells in St. Louis Park. Using the PAH data derived from water samples at SLP15 taken from July 16, 1979 through December 7, 1982 (as reported by CH2M Hill 1982, see also

TABLE I4-2

LIST OF INDIVIDUAL PAH COMPOUNDS ANALYZED

IN ST. LOUIS PARK WELLS AND BY STUDIES OF OTHER WATER SUPPLIES

	St. Louis Park Wells[a]				Other Water Supply Studies[b]									
Compounds	MDH	CH2M Hill	Capsule	MRC	Acheson	Alben	Benoit	Borneff & Kunte	Crane	Lewis	Quaghebeur & DeWulf	Sorrell	Saxena	Williams
Acenaphthylene	X	X	X	X			X							
Acenaphthene		X	X	X										
Anthracene	X	X	X	X		X	X					X		X
Benzo(a)Anthracene	X	X	X	X	X		X	X				X		X
Benzo(a)Pyrene	X	X	X	X	X			X	X	X	X		X	
Benzo(b)Fluoranthene		X	X					X	X		X	X		
Benzo(c)Phenanthrene	X			X										
Benzo(e)Pyrene	X	X			X							X		
Benzo(g,h,i)Perylene	X	X	X	X	X			X	X	X	X	X	X	
Benzo(j)Fluoranthene	X				X			X					X	
Benzo(k)Fluoranthene	X	X	X		X			X	X	X	X	X	X	
Chrysene	X	X	X	X	X		X					X		
Dibenzo(a,c)Anthracene	X													
Dibenzo(a,h)Anthracene		X	X									X		
Fluorene	X	X	X	X		X	X							
Fluoranthene	X	X	X	X	X	X	X	X	X	X	X		X	X
Indeno(1,2,3-cd)Pyrene	X	X	X	X	X			X	X	X	X	X	X	
Perylene	X	X		X	X							X		
Phenanthrene	X	X	X	X		X	X						X	X
Pyrene	X	X	X	X	X	X	X	X				X		X
4,5,9,10-tetrahydropyrene	X													

TABLE I4-2 (Continued)

Compounds	St. Louis Park Wells[a]				Other Water Supply Studies[b]									
	MDH	CH2M Hill	Capsule	MRC	Acheson	Alben	Benoit	Borneff & Kunte	Crane	Lewis	Quaghebeur & DeWulf	Sorrell	Saxena	Williams
Acridine		X												
Benzo(b)Thiopene		X												
Carbazole		X												
Indole		X												
Quinoline		X												
Biphenyl	X	X		X			X							
2,3-Dihydroindene		X												
Indene		X												
1-Methylanaphthalene		X		X										
2-Methylnaphthalene	X	X		X										
Napththalene		X	X	X		X	X							X
Phenanthridine		X												
Methylnaphthalene							X							X
Dimethnylnaphthalene							X							X
Bibenzyl							X							
1-Methylphenanthrene							X							
Triphenylene							X							
1-Methylpyrene												X		
Tri-Methylnaphthalenes														X
Dimehthlbiphenol														X
Mehtylanthracene														X
Stilbene														X

Notes: (a) See Appendix K.
(b) See Table I4-1.

TABLE I4- 3
AGGREGATE PAH AND OXYGENATED-PAH CONCENTRATIONS IN
GREAT LAKES MUNICIPAL DRINKING SUPPLIES ON TWO SAMPLING DATES*

Municipality	Date	Total Concentration of PAH and Oxygenated-PAH, nanograms per liter
Thunderbay	Jan. 1980	49.1
	Aug. 1980	39.7
Sault Ste. Marie	Jan. 1980	684.8
	Aug. 1980	3144.1
Owen Sound	Jan. 1980	128.7
	Aug. 1980	116.4
Godrich	Jan. 1980	173.1
	Aug. 1980	51.5
Sarnia	Jan. 1980	30.2
	Aug. 1980	9.6
Amherstburg	Jan. 1980	122.2
	July 1980	15
Union-Leamington	Jan. 1980	214.8
	July 1980	268.6
Port Dover	Jan. 1980	351.9
	July 1980	54.3
Port Colborne	Jan. 1980	268.4
	Aug. 1980	57.3
St. Catherines	Jan. 1980	686.2
	Aug. 1980	34
Toronto	Jan. 1980	169.2
	Aug. 1980	21.4
Kingston	Jan. 1980	179.1
	Aug. 1980	60.5
Average	Jan. 1980	254.8
Average	July/Aug. 1980	322.7

*Adapted from Williams, et al. (1982)

TABLE I4-4

HIGHEST INDIVIDUAL PAH AND OXYGENATED PAH CONCENTRATIONS DETECTED IN FINISHED DRINKING WATER FROM TWELVE GREAT LAKES MUNICIPALTIES*

Compound	Highest Concentration Detected, nanograms per liter	Site	Date
Naphthalene	1271	Sault Ste. Marie	Aug. 1980
Methyl Naphthalene	107	Sault Ste. Marie	Aug. 1980
Dimethyl Naphthalenes	83	Port Dover	Jan. 1980
Trimethyl Naphthalenes	22	St. Catherines	Jan. 1980
Biphenyl	32	Sault Ste. Marie	Jan. 1980
Bibenzyl	5	Toronto	Aug. 1980
Fluorene	105	Sault Ste. Marie	Aug. 1980
Phenanthrene/Anthracene	1269	Sault Ste. Marie	Aug. 1980
Dimethyl Biphenyl	12	Port Dover	July 1980
Fluoranthene	85	Sault Ste. Marie	Aug. 1980
Pyrene	72	St. Catherines	Jan. 1980
Methyl Anthracene	80	St. Catherines	Jan. 1980
Stilbene	13	St. Catherines	Jan. 1980
Fluorenone	31	St. Catherines	Jan. 1980
Anthraquinone	72	Sault St. Marie	Aug. 1980

only 5 municipalities here -

*Samples taken on two occasions per municipality; adapted from Williams, et al. (1982).

Appendix K), it can be calculated that the average total PAH concentration in the well water was 6.0 micrograms per liter. This aggregate average is comprised of 0.022 micrograms per liter carcinogenic PAH and 5.98 micrograms per liter noncarcinogenic PAH. Comparing this average total PAH concentration in well SLP15 with the concentrations occurring in ground water (shown in Table I4-1), it can be seen that, in general, the PAH levels in other ground water samples are 20 to 2,000 times lower in concentration than the average total PAH concentration in well SLP15. However, when compared to the drinking water generated at the Sault Ste. Marie treatment plant on August 1980 (Table I4-3), the average total PAH levels in well SLP15 are only about twice the former. It should be emphasized that the water containing about 3 micrograms per liter at Sault Ste. Marie is used as a drinking water supply.

If there has been a general lack of data documenting the PAH levels in raw water supplies, there is a greater lack of information on PAH levels in distributed drinking water. Recent evidence suggests that water distributed through pipes coated with coal tar pitches or enamels may become contaminated with PAH. For instance, Crane, et al (1980) determined that ground water, having an initial fluoranthene concentration less than 10 nanograms per liter, after traveling through coal tar-lined pipes contained, on the average, 284 nanograms per liter fluoranthene. Likewise, Alben (1980) determined that concentrations of specified PAH compounds in water storage tanks coated with coal tar increased 5 to 30 times, compared to the influent concentrations. Thus, the PAH concentrations in treated surface waters or ground waters listed in Table I4-1, if used to assess the exposure to humans to PAH via the drinking water route, may lead to an underestimation of PAH exposures, if water is distributed through coal-tar lined pipes.

As stated previously, PAH concentrations in water supplies vary widely. An attempt was made to determine typical PAH concentrations in water supplies as well as the range of the PAH concentrations, in order to facilitate an assessment of typical PAH contribution via

ingestion from water sources compared to total human intake. A distillation of relevant data from Table I4-1 is presented in Table I4-5. These data are subdivided into two categories: finished water (which includes ground and treated surface waters) and raw surface water supplies. The range of PAH concentrations in Table I4-5 was obtained by determining the lowest and highest carcinogenic, noncarcinogenic and total PAH concentrations in a certain type of water supply from the appropriate studies listed in Table I4-1. The typical concentrations in Table I4-5 were assessed by determining the median concentrations associated with carcinogenic, noncarcinogenic, and total PAH for finished and raw surface waters from the averaged results in Table I4-1. Since distribution of PAH could not be accurately determined, due to an insufficient data base, median values (as opposed to mean values) were used as a measure of typical concentration. Since median results are reported, it is not surprising that, in some cases, the sum of typical carcinogenic and noncarcinogenic PAH concentrations does not equal the typical total PAH concentration.

As shown in Table I4-5, the typical carcinogenic, noncarcinogenic, and total PAH concentrations in raw surface waters are approximately 300, 9, and 15 times as high as their respective typical values in finished water. While the ratio of noncarcinogenic to carcinogenic PAH in finished water is 23 to 1, the ratio in raw surface water is 0.8 to 1. This result indicates that treatment of surface water may be more effective at removing carcinogenic PAH than noncarcinogenic PAH.*

*A discussion of PAH in other water supplies compared to PAH in St. Louis Park well SLP15 is also provided in appendix G, Section G3, from a somewhat different perspective.

TABLE I4-5

SUMMARY OF RELEVANT PAH CONCENTRATIONS IN WATER SUPPLIES

(All concentrations in nanograms per liter)

	Carcinogenic PAH		Non-Carcinogenic PAH		Total PAH		
Water Supply	Range of Averages	Typical	Range of Averages	Typical	Range of Averages	Typical	Highest Concentration Detected
Finished water (ground or treated surface)	0-41	0.9	2-280	21	3-310	29	3055
Raw surface water	0-886	245	37-387	195	60-1273	440	2826

I5. ESTIMATION OF PAH INTAKE FROM VARIOUS SOURCES

An estimation of daily human intake of PAH from various ambient sources is presented in Table I5-1. The data in this table should not be viewed as precise human intakes, but rather as very approximate quantities to provide references points for comparing contributions from various environmental media. This is due, in large part, to the fact that PAH levels are variable in the ambient environment and intakes are highly dependent on personal behavior (such as smoking habits and eating preferences). The estimate of human intake via the air route is taken from Santodanato, et al. (1981). The intake of carcinogenic PAH via air includes contributions only from benzo[a]pyrene, benzo[j]fluoranthene and indeno[1,2,3-cd]pyrene, and, thus, is a conservative estimate of carcinogenic PAH intake from air. The range of total PAH levels in food as determined by Santodonato, et al. (1981) is 1.6 to 16 micrograms per day. The percentage of this range as carcinogenic PAH is not possible to determine due to insufficient data. However, based on the fact that the carcinogenic PAH contribution to total PAH from both air and water sources is approximately 17%, it is similarly estimated that the total carcinogenic PAH intake from food ranges from 0.3 to 3.0 micrograms per day.

Using the data presented in Table I4-5 for typical concentrations of carcinogenic, noncarcinogenic, and total PAH compounds in finished and raw surface waters, and assuming that a person ingests 2 liters of water per day, the estimated human intakes from typical drinking and raw surface waters presented in Table I5-1 were obtained. The higher estimates for human intake, shown in this table as "highest average" values, were obtained from the highest average carcinogenic, noncarcinogenic and total PAH concentrations occurring in finished water (41, 280, and 310 nanograms per liter, respectively) from Table I4-5. It should be reiterated that the summation of carcinogenic and noncarcinogenic PAH loads from water sources should not necessarily equal the total PAH load due to the fact that their calculations were based on median PAH concentrations in Table I4-1, as described previously. As can be seen from Table I5-1, air and water are minor

TABLE I5-1

ESTIMATED HUMAN INTAKE OF PAH FROM VARIOUS AMBIENT SOURCES
(Micrograms per Day)

Source	Carcinogenic	Non carcinogenic	Total
Air (typical)[a]	0.038	0.17	0.21
Food (typical)	0.3-3.0	1.3-13	1.6-16[a]
Finished drinking water (typical)	0.0018	0.042	0.058
Finished drinking water (highest average)	0.082	0.560	0.620
St. Louis Park Well #15, untreated (average)[b]	0.044	11.9	12.0
Raw surface (typical)	0.49	0.39	0.88

Notes:

(a) From Santodonato, et al. (1981).

(b) Using average of analyses from July 16, 1979 to December 7, 1982 reported by CH2M Hill 1982.

contributors to human intake of carcinogenic and noncarcinogenic PAH compared to food. Typical air and drinking water exposures would contribute only 2 to 14 percent of the total PAH intake, using the two extremes of the food contributions shown in Table I5-1.

The average carcinogenic, noncarcinogenic and total PAH concentrations in water from well SLP15 presented previously were also used to generate intake estimates in Table I5-1. It is interesting to note that the carcinogenic PAH load from SLP15 is comparable to the carcinogenic PAH load due to ambient air and lower than that associated with ingestion of raw surface water or finished drinking water (highest average). However, the noncarcinogenic PAH load from SLP15 is much higher compared to all other sources, except that associated with the high PAH intake range from food. In short, if 2 liters of water from SLP15 would be ingested per day without further treatment, it would be expected that the carcinogenic PAH load in man would be increased only slightly compared to typical human intakes elsewhere, while the noncarcinogenic load would be increased by a factor of 2 to 9, depending on the estimated contribution from food.

I6. CONCLUSIONS AND RECOMMENDATIONS

Considerable data have been collected regarding the identity and amount of certain PAH in the untreated ground water supply of the St. Louis Park municipal water supply system. The analysis carried out on this water supply is, in many respects, far more comprehensive than any surveys conducted on other waters in the United States. Thus, it is difficult to compare the results of the St. Louis Park study with similar analyses of other ground, surface, or finished drinking water supplies. Because only a few individual PAH have historically been monitored in water on a routine basis, it is likely that most reported PAH concentrations in raw and finished waters have probably underestimated the total PAH loadings.

From the available data it is apparent that PAH concentrations in water vary widely, and may be influenced by treatment practices and the distribution system. In general, it appears that levels of noncarcinogenic PAH in some of the St. Louis Park wells (e.g., well SLP15) are higher than typical concentrations found in raw and finished waters in the United States and Canada. Levels of carcinogenic PAH in the St. Louis Park wells, on the other hand, are similar to values reported for other waters.

Human intake of PAH from environmental sources occurs by inhalation and by ingestion of PAH contained in foods and drinking water. Therefore, it is important to examine the total body burden of PAH resulting from all media when considering possible health risks related to exposure. Quantitative estimates of total human intake of PAH, however, require numerous assumptions concerning conformity of lifestyle and the lack of confounding variables attributed to geographic location, general state of health, etc. Nevertheless, it is possible to examine relative contributions to total intake which can reasonably be expected from food, ambient air, and drinking water.

The available data summarized in this report and elsewhere (Santodonato, et al. 1981) indicate that PAH intake from ambient air and water constitutes only a minor portion of total exposure, with

food making the major contribution. Typically, the intake of PAH from air and water would contribute only 2% to 14% of the total exposure. When the PAH monitoring data from St. Louis Park water are used in calculating total intake by that population, the exposure to carcinogenic PAH from drinking water would be consistent with the typical situation encountered elsewhere as indicated above. Intake of noncarcinogenic PAH, however, could be significantly elevated by ingestion of certain untreated St. Louis Park waters, possibly reaching levels comparable to the typical intake from food. An increased intake of PAH from drinking water would not be expected, however, to result in increased deposition or storage of PAH in the body, since PAH are known to be rapidly metabolized and excreted (Santodonato, et al. 1981).

The presently available toxicologic data are inadequate for derivation of individual criteria for acceptable levels of exposure to each individual PAH compound. Instead, a more generic approach has been taken in which PAH are categorized as either carcinogenic or noncarcinogenic, and criteria are developed only for these two categories. This approach is consistent with the procedure followed by the U.S. EPA (1980a) in developing ambient water quality criteria for PAH, and correctly acknowledges the limitations of the data base for risk assessment purposes.

The criteria developed here apply to PAH and heterocyclic PAH, also including their alkylated derivatives, as defined in the Definition of Terms section of this report. The criteria are limited to these classes of compounds because other heterosubstituted PAH are not found in untreated water from St. Louis Park municipal supply wells.

I6.1 Carcinogenic PAH Criterion

The ambient water quality criterion for the sum of all carcinogenic PAH is 28 nanograms per liter according to the current U.S. EPA (1980a) recommendations. This value is based on a mathematical extrapolation of animal bioassay data for benzo[a]pyrene,

using the conservative assumption that all carcinogenic PAH are equal in potency to benzo[a]pyrene. The criterion represents a very stringent estimate of the allowable concentration of carcinogenic PAH in ambient water which will keep the lifetime risk for cancer development below one chance in 100,000. In the present report the 28 nanograms per liter criterion for carcinogenic PAH is accepted as the best currently available value to provide for adequate protection of public health.

In putting the recommended criterion into practice it is necessary to assume that all carcinogenic PAH can be identified and measured in water. This is a reasonable assumption taking into account the fact that a large number of PAH have been tested for carcinogenic activity over the past five decades. Thus, it is reasonable to expect that the major carcinogenic PAH are recognized and, further that the great majority of these carcinogens are simple derivatives of benz[a]anthracene, chrysene, benzo[a]pyrene, benzo[c]phenanthrene, dibenz[a,h]anthracene, and cholanthrene. In addition, among the carcinogenic heterocyclic analogs of PAH nearly all seem to be simple derivatives of benz[a]acridine, benz[c]acridine, dibenzacridines, and dibenzocarbazoles. It is recommended, however, that if newly discovered carcinogenic PAH are reported that these substances be included in the 28 nanograms per liter criterion. For PAH which have not been tested for carcinogenicity and which are not simple derivatives of the structures listed above, it is recommended that they be considered noncarcinogenic for risk assessment purposes.

I6.2 Noncarcinogenic PAH Criterion

The approach taken in this report to derive exposure criteria for noncarcinogenic PAH is based on reported "no-effect" levels for chronic exposure of mammals to carcinogenic PAH. This somewhat unconventional approach is made necessary by the virtual absence of appropriate chronic bioassay data for noncarcinogenic PAH or PAH mixtures. Although uncertainties are likely to occur with such extrapolations, it is believed that in the case of PAH any errors in the approach are likely to overestimate rather than underestimate

actual health risks. Using a conservative approach with regard to application of uncertainty factors and assumptions concerning the quality of the data base, recommended levels of noncarcinogenic PAH in water based on potential for producing adverse health effects fall in the range of 100 to 400 micrograms per liter, assuming that water contributed all of the exposure. These concentrations correspond to acceptable daily intakes of 200 to 800 micrograms per day.

The toxicity-based criterion for noncarcinogenic PAH is worthy of review. If the highest no observed adverse affect level (NOAEL) from the 3-methylcholanthrene and benzo[a]pyrene toxicity studies utilizing an uncertainty factor of 100 as a safety factor were used, this would lead to criterion concentrations of about 120 and 370 micrograms per liter, respectively. As noted in the National Academy of Sciences report "Drinking Water and Health "(NAS 1977, pg. 804), the uncertainty factor of 100 would apply under the following circumstances.

> Experimental results of studies of human ingestion not available or scanty (e.g., acute exposure only). Valid results of long-term feeding studies on experimental animals or, in the absence of human studies, valid animal studies on one or more species. No indication of carcinogenicty. Uncertainly factor = 100.

It is judged that the animal feeding studies fit the above characterization, and that the National Academy of Sciences report suggesting a safety factor of 1000 for "scanty results on experimental animals" would certainly not apply. In the absence of specific information about the similar toxicological (but not including carcinogenic) effects of other PAH, it would, therefore, be reasonable to use a criterion in the range of 100 to 400 micrograms per liter for the total concentration of all noncarcinogenic PAH.

For substances where exposure occurs from several media, it is necessary to consider a partitioning of the acceptable daily

intake (ADI) among air, water, and food. In suggesting criteria for such noncarcinogens, the National Academy of Sciences assumes that as little as 20 percent or one percent contribution from water might apply (NAS 1977, pg. 796). In the case of PAH, however, the contribution from air and food is likely to be in the range of 1 to 14 micrograms per day, which represents a relatively insignificant contribution to the total ADI. Thus, in the development of criterion here it is recommended that the limit for noncarcinogenic PAH be fully assigned to the water ingestion route of exposure.

The U.S. EPA ambient water quality criterion for fluoranthene, based on the chronic toxicity of this noncarcinogenic PAH, is 42 micrograms per liter, taking into account both direct water intake, as well as ingestion of fluoranthene in fish (U.S. EPA 1980b). This criterion translates to 200 micrograms per liter if consumption of contaminated fish is excluded, as is appropriate for a ground-water application. This criterion is similarly based on the use of an uncertainity factor related to the quality of the animal experimental data, as well as the relative contributions of food and water intake assuming daily ingestion of a certain quantity of fish. It is important to note that this water quality criterion is the only one promulgated to date by the EPA based on an estimate of human toxicity from a noncarcinogenic PAH.

The range of 100 to 400 micrograms per liter*, which is adequate to protect against adverse health effects resulting from noncarcinogenic PAH, also happens to encompass many reported organoleptic effects concentrations, as well as extrapolations from mammalian toxicity studies. As discussed in Section I3, the cited organoleptic (taste and odor) effects range from 4 to 6,800 micrograms per liter, which includes the value of 20 micrograms per liter for acenaphthene, the only EPA criterion limit for any PAH based on organoleptic effects (U.S. EPA 1980c). The lowest value of 4 micrograms per liter refers to coal tar itself. However, as noted

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*Concentrations are rounded off from the values derived from 3-methylcholanthrene and benzo[a]pyrene, respectively.

previously, the PAH profiles in St. Louis Park are not consistant with that of coal tar, but are more like creosote, for which the cited organoleptic effect is 125 micrograms per liter.

In summary, the criteria for both organoleptic effects and estimated human toxicities, considering both uncertainty factors and contributions from food and water, lead to criterion limits for total noncarcinogenic PAH encompassing a range of 4 to 400 micrograms per liter, where the lower bound of this range reflects the lowest concentration at which organoleptic effects could occur. Considerable conservatism has been utilized in estimating this range; nevertheless, it would not be unreasonable, in the interest of erring on the side of caution, to establish a limit for potable waters towards the lower end of this range.

Another perspective to be considered in relation to the organic water quality of St. Louis Park municipal supply wells is the gross organic load as measured by its total organic carbon (TOC) content, typically in the range of 2 to 3 milligrams per liter (see Appendix G). Although this is somewhat high, it is not unusually so, for finished public water supplies. This concentration range corresponds to about the 80th percentile found for TOC by the U.S. Environmental Protection Agency in a study of 80 U.S. public water supplies (Symons 1975). Thus, although the PAH in the contaminated St. Louis Park municipal supply wells may be of concern, the total organic load is not unusual.

Finally, it should be noted that, although the significance of noncarcinogenic PAH should be evaluated for human health and other human effects, such as taste or odor concerns, another consideration is whether these compounds are unusually high in concentrations compared to other public water supplies. As pointed out in Section I4, this appears to be the case, even though one finished Canadian municipal supply water was found to be comparable to untreated water from contaminated St. Louis Park wells. It should also be emphasized, however, that in almost all cases the evaluation of PAH in other water supplies have not approached the extent, frequency, and comprehensiveness of that of wells in St. Louis Park.

I6.3 Conclusion

Finished waters from all of the currently closed municipal supply wells in St. Louis Park and Hopkins meet the above-recommended health-related criteria for carcinogenic and noncarcinogenic PAH (see Chapter 4). Three of the seven closed wells (SLP5, SLP10 and SLP15) exceed the lowest reasonable criterion that might be established to protect against objectionable taste or odors. Nevertheless, it must be recognized that the levels of PAH in some of these wells, although not representing a health threat, are abnormally high in comparison to other water supplies where PAH monitoring data are available.

A long standing principle in public water supply, noted by the U.S. Environmental Protection Agency in the appendix to its Interim Primary Drinking Water Regulations (U.S. EPA 1976b), is that the best available source should be used:

> Production of water that poses no threat to the consumer's health depends on continuous protection. Because of human frailties associated with protection, priority should be given to selection of the purest source. Polluted sources should not be used unless other sources are economically unavailable, and then only when personnel, equipment, and operating procedures can be depended on to purify and otherwise continuously protect the drinking water supply.

In addition to the criterion of best available source already addressed, this statement specifically focuses on economics and dependability. Thus, any decisions on utilization of contaminated municipal supply wells in St. Louis Park should also consider alternative sources and the likely perception of the public in being exposed to unusual concentrations of trace chemicals, even when an assessment of health impacts does not identify a significant risk.

I7. REFERENCES

Alben, K. 1980. Coal Tar Coatings of Storage Tanks. A Source of Contamination of the Potable Water Supply. Environmental Science & Technology, 14 (4), 468-470.

Albert, R.E., R.E. Train and E. Anderson. 1977. Rationale developed by the Environmental Protection Agency for the assessment of carcinogenic risk. J. Natl. Cancer Inst. 58: 1537.

Acheson, M.A., R.M. Harrison, R. Perry, and R.A. Wellings. 1976. Factors affecting the Extraction and Analysis of Polynuclear Aromatic Hydrocarbons in Water. Water Research, 10, 206-212.

Lewis, W.M., 1975. Polynuclear Aromatic Hydrocarbons in Water. Water Treatment and Examination, 23, 243-277.

ASTM (American Society for Testing and Materials). 1978. Compilation of Odor and Taste Threshold Values Data. ASTM Data Series DS 48A, Philadelphia, PA.

Arcos, J. and M.F. Argus. 1974. Chemical Induction of Cancer. Bol. 11A. Academic Press, NY.

Benoit, F.M., G.L. LaBell and D.T. Williams. 1979. Polycyclic Aromatic Hydrocarbon Levels in Eastern Ontario Drinking Waters, 1978. Bull. Environm. Contam. Toxicol. 23, 774-778.

Borneff, J. and H. Kunte. 1964 Carcinogenic Substances in Water and Soil Part XVI. Evidence of Polynuclear Aromatics in Water Samples through Direct Extraction. Arch. Hyg. (Berl.), 148, 585-597.

Boutwell, R.K. and D.K. Bosch. 1958. The carcinogenicity of creosote oil: Its role in the induction of skin tumors in mice. Cancer Res. 18: 1171-1175.

Burttschell, R.H., A.A. Rosen, F.M. Middleton and M.B. Ettinger. 1959. Journal of the American Water Works Association. February 1959. Pages 205-214.

CH2M Hill. 1982. Evaluation of Groundwater Treatment Alternatives: St. Louis Park, Minnesota. Project Element D Technical Memorandum. Well Sampling and Analysis Program. Prepared by M.R. Harris, H.E. Cole and J.T. Fleissner. November 29, 1982.

Cookson, H.A. 1924. Epithelioma of the skin after prolonged exposure to creosote. Br. Med. J. 1:368.

Crane, R.I., M. Fielding, T.M. Gibson, and C.P. Steel, 1980.* A Survey of Polycyclic Aromatic Hydrocarbon Levels in British Waters. Medmenham Laboratory, Water Research Centre, U.K. 47 pages.

*No publication date given. 1980 is earliest possible date inferred from listed references.

Dipple, A. 1976. Polynuclear Aromatic Carcinogens. In: Chemical Carcinogens, C.E. Searle, Ed. ACS Monograph 173, pp. 245-314.

Doll, R., M.P. Vessey, R.W.R. Beasley, A.R. Buckley, E.C. Fear, R.E.W. Fisher, E.J. Gammon, W. Gunn, G.O. Huges, K. Lee and G. Norman-Smith, 1972. Mortality of gasworkers - Final report of a prospective study. Br. J. Ind. Med. 29: 394-406.

Falk, E.L., P. Kotin and S. Thompson 1964. Inhibition of Carcinogenesis. the effect of Polycyclic Hydrocarbons and Related compounds. Arch. Envision. Health 9:169-179.

Haddow, A., C.M. Scott and J.D. Scott. 1937. The influence of certain carcinogenic and other hydrocarbons on body growth in the rat. Proc. Roy. Soc. London B. 122: 477-507.

Haldin-Davis, H. 1935. Multiple warts in a creosote worker. Proc. Roy. Soc. Med. 29: 89-90.

Hammond, E.C., et. al., 1976. Inhalation of benzpyrene and cancer in man. Ann. NY Acad. Sci. 271: 116.

Hoch-Ligeti, C. 1941. Studies on the changes in the lymphoid tissues of mice treated with carcinogenic and non-carcinogenic hydrocarbons. Cancer Res. 1: 484.

Homburger, F., C.G. Van Dongen, R.A. Adams, E.A. Soto and K.J. Pai. 1978. An experimental approach to the breast cancer, reserpine problem. Cancer Lett. 4(3): 177-183.

Horton, A.W., R. Tye and K.L. Stemmer. 1963. Experimental carcinogenesis of the lung. Inhalation of gaseous formaldehyde or an aerosol of coal tar by C3H mice. J. Natl. Cancer Inst. 30: 31-43.

Kinkead, E.R. 1973. Toxicity of coal tar aerosol, in Proceedings of the Fourth Annual Conference of Environmental Toxicology, Fairburn, OH. October 16-18, pp. 177-188.

Lenson, N. 1956. Multiple cutaneous carcinoma after cresote exposure. New Engl. J. Med. 254: 520-522.

Lijinsky, W., U. Saffiotti and P. Shubik. 1957. A study of the chemical constitution and carcinogenesis action of creosote oil. J. Natl. Cancer Inst. 18: 687-692.

MacEwen, J.D., A. Hall and L.D. Scheel. 1976. Experimental oncogenesis in rats and mice exposed to coal tar aerosols. Presented before the Seventh Annual Conference on Environmental Toxicology, Dayton, OH. October 16, pp.

MacEwen, J.D. and E.H. Vernot. 1976. Carcinogenic effects of chronic inhalation exposure of animals to coal tar aerosol. Toxic Hazards Research Unit Annual Technical Report: 1976 Aerospace Medical Research Laboratory. Wright-Patterson Air Force Base, OH. AMRL-TR-76-57.

McConnell, E.E. and H.D. Specht. 1973. Lesions found in animals exposed to coal tar aerosols, in Proceedings of the Fourth Annual Conference on Environmental Toxicology, Fairburn, OH. October 16-18, pp. 189-198.

NAS (National Academy of Sciences). 1977. Drinking Water and Health. National Academy of Sciences, Washington, DC.

Neal, J. and R.H. Rigdon. 1967. Gastric tumors in mice fed benzo[a]pyrene: A quantitative study. Tex. Rep. Biol. Med. 25: 553.

Pfeiffer, E.H. 1973. Investigations on the carcinogenic burden by air pollution in man. VII. Studies on the oncogenetic interaction of polycyclic aromatic hydrocarbons. Abl. Bakt. Hyg., I. Abt. Orig. B. 158: 69.

Pfeiffer, E.H. 1977. Oncogenic interaction of carcinogenic and non-carcinogenic polycyclic aromatic hydrocarbons in mice. In: V. Mohr, et. al., Eds. Air Pollution and Cancer in Man. Intl. Agency Res. Cancer Sci. Publ. No. 16. p. 69.

Quaghebeur, D. and E. DeWulf. 1978. Polynuclear Aromatic Hydrocarbons in the Main Belgium Aquifers. The Science of the Total Environment, 10, 231-237.

Rakhmanina, N.L. 1964. Establishing standards for the phenanthrene and pyrene contents in water bodies. Gigiena i Sanit. 29(6): 19-23.

Redmond, C.K., A. Ciocco, J.W. Lloyd and H.W. Rush. 1972. Long-term mortality study of steelworkers. J. Occup. Med. 14(8): 621-629.

Redmond, C.K., B.R. Strobino and R.H. Cypess. 1976. cancer experience among coke by-product workers. Ann. NY Acad. Sci. pp. 102-115

Redmond, C.K., H.S. Wieand, H.E. Rockette, R. Sass and G. Weinberg. 1979. Long-term mortality experience of steelworkers. Prepared for the U.S. National Institute for Occupational Safety and Health, Cincinnati, OH. June, 1979. Contract No. HSM-99-71-32.

Roe, F.J.C., D. Bosch and R.K. Boutwell. 1958. The carcinogenicity of creosote oil: The induction of lung tumors in mice. Cancer Res. 18: 1176-1178.

Saxena, J., D.K. Basu, and J. Kozuchowski, 1977. Method Development and Monitoring of Polynuclear Aromatic Hydrocarbons in Selected U.S. Waters. Health Effects Research Laboratory (U.S.E.P.A.), TR-77-563. 1979.

Santodonato, J., P. Howard and D. Basu. 1981. Health and ecological assessment of polynuclear aromatic hydrocarbons. J. Environ. Pathol. Toxicol. 5: 1-364.

Schmahl, D., et. al., 1977. Syncarcinogenic action of polycyclic hydrocarbons in automobile exhaust gas condensates. In: V. Mohr, et. al., Eds. Air Pollution and Cancer in Man. Intl. Agency Res. Cancer Sci. Publ. No. 16. p. 53.

Shear, M.J. 1938. Studies in carcinogenesis. V. Methyl derivatives of 1,2-benzanthracene. Am. J. Cancer. 33: 499-537.

Shear, M.J. 1941. Studies in carcinogenesis. XVI. Production of subcutaneous tumors in mice by miscellaneous polycyclic compounds. J. Natl. Cancer Inst. 2: 241-258.

Shubik, P. and G. Della Porta. 1957. Carcinogenesis and acute intoxication with large doses of polycyclic hydrocarbons. Arch. Pathol. 64: 691-703.

Snell, K.C. and H.L. Stewart. 1962. Induction of pulmonary adenomatosis in DBA/2 mice by the oral administration of dibenz[a,h]anthracene. Acta. Un. Int. Canc. 19: 692.

Sorrell, R.K., R. Reding, H.J. Brass, 1979. Analysis of Polynuclear Aromatic Hydrocarbons in Selected Water Supplies. 177th National Meeting of American Chemical Society, Division of Environmental Chemistry, Honolulu, Hawaii, April 1-6, 1979.

Stara, J.F., D. Kello and P. Durkin. 1980. Human health hazards associated with chemical contamination of aquatic environment. Environ. Health Perspect. 34: 145-158.

Thyssen, J., J. Althoff, G. Kimmerle and U. Mohr. 1981. Inhalation studies with benzo[a]pyrene in Syrian golden hamsters. J. Natl. Cancer Inst. 66(3): 575-577.

Tye, R. and K.L. Stemmer. 1967. Experimental carcinogenesis of the lung. II. Influence of phenols in the production of carcinoma. J. Natl. Cancer Inst. 39: 175-186.

U.S. EPA. 1976a. Quality Criteria for Water. U.S. Environmental Protection Agency. EPA-440/9-76-023.

U.S. EPA. 1976b. National Interim Primary Drinking Water Regulations. Appendix A. EPA-570/9-76-003.

U.S. EPA. 1980a Ambient Water Quality Criteria for Polynuclear Aromatic Hydrocarbons. EPA-440/5-80-069.

U.S. EPA. 1980b. Ambient Water Quality Criteria for Fluoranthene. EPA-440/5-80-049.

U.S. EPA. 1980c. Ambient Water Quality Criteria for Acenaphthene. EPA-440/5-80-015.

U.S. EPA. 1980d. Ambient Water Quality Criteria for Acenaphthylene.

U.S. EPA. 1980e. Ambient Water Quality Criteria for 2,4-Dimethylphenol. EPA-440/5-80-044.

U.S. EPA. 1980f. Ambient Water Quality Criteria for Phenol.

U.S. EPA. 1980g. Ambient Water Quality Criter for Cholorinated Phenols. EPA-440/5-80-032.

U.S. EPA. 1980h. Ambient Water Quality Criteria for 2-Cholrophenol. EPA-440/5-80-034.

U.S. EPA. 1980i. Ambient Water Quality Criteria for 2,4-Dichlorophenol. EPA-440/5-80-042.

U.S. EPA. 1980j. Ambient Water Quality Criteria for Naphthalene. EPA-440/5-80-059.

Wallcave, L., H. Garcia, R. Feldman, W. Liginsky and P. Shubik. 1971. Skin tumorigenesis in mice by petroleum asphalts and coal-tar pitches of known polynuclear aromatic hydrocarbon content. Toxicol. Appl. Pharmacol.

Williams, D.T., E.R., Nestman, G.L. LeBel, F.M. Benoit, and R. Oston, 1982. Determination of Mutagenic Potential and Organic Contaminants of Great Lakes Drinking Water. Chemosphere, (11)3, 263-276.

World Health Organization. 1971. International Standards for Drinking Water. WHO, Geneva.

Yoshida, H. and R. Fukunishi. 1977. Mammary tumor and leukemia in male Sprague-Dawley rats evoked by a series of intragrastric administration of 7,12-dimethylbenz(a)anthracene. Gann. 68: 237-239.

APPENDIX J

COMPLIANCE MONITORING STANDARDS FOR PAH CRITERIA

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J1. OBJECTIVES

Since PAH's have contaminated aquifers which are used as drinking water supplies, in order to determine if source water is safe for human consumption (its most critical use) and to determine if possible treatment processes are working effectively, a criteria needs to be established to which source water can be compared. The following sections discuss a recommended approach for a PAH drinking water criteria. It demonstrates the types of considerations which must be addressed prior to establishing guidelines or taking regulatory action. A careful review of existing data should lead to a final determination of a specific criteria and procedures for criteria verification.

The most basic component of the compliance monitoring standard is the list of contaminants. The list must include all of the contaminants, within the chemical classification being regulated, which have been shown to be present in the ground water at sufficient concentrations to impact the calculation of total criteria concentration. The chemical classification being regulated often includes many compounds never identified in the sources being sampled. However, including all compounds, whether identified in the source, usually creates unecessary data generation at increased cost. Therefore, the final contaminant list should be limited in scope to those contaminates of significant interest. Rationale and justification for the recommended PAH criteria standard approach is discussed in Section J2.

The location and frequency of sampling must be designed to protect the public health as a first priority. The extent of present contamination, or the probability of future contamination, defines geographical areas within which long-term systematic sampling is required. Likewise, the same factors dictate the frequency with which each of the defined areas should be sampled. The recommended approach to location and frequency of sampling for the PAH criteria standard are discussed in Sections J3 and J4.

Once data has been generated for a particular complicance monitoring round, the data will be compared to the compliance criteria. This comparison is the critical decision point. The future use of a water source and the possibility of enforcement litigation are just two of many concerns which rely on the outcome of the data and its comparison to the standard criteria. Therefore, the manner in which this comparison is made is critical. The interpretation of the analytical data generated by the compliance monitoring standard and the subsequent calculation of PAH concentration are discussed in Section J5.

The end result of this compliance monitoring standard is to accurately determine compliance with the criteria. The obvious complement to this result is the action to be taken when the criteria is exceeded. Once exceedance has been demonstrated for a set of monitoring data, a train of events must begin which systematically confirms or belies the exceedance and in the case of confirmation, leads to affirmative action toward insuring continued protection of the public health. Enforcement of the PAH compliance monitoring standard is discussed in section J6.

In order to assure consistency between analytical data, specific sampling and analysis protocol must be used. Continued demonstration of analytical integrity through implementation and maintenance of a quality assurance program is critical anytime litigation is a possibility. Section J7 discusses a recommended sampling and analysis protocol.

The costs associated with compliance monitoring depend upon the number of wells in each group, the frequency of sampling, and whether the analysis includes the primary or secondary lists. Section J8 discusses the cost considerations relevant to the proposed compliance monitoring.

As discussed in Section 6.4, an alternative to treatment of wells for removal of PAH, is the abandonment of contaminated wells and replacement with new wells. If this option is chosen, surveillance monitoring, for the purpose of evaluating existing and new wells, will be required. The guidelines discussed in Sections J2-J7 are equally applicable to surveillance monitoring.

J2. RECOMMENDED MONITORING APPROACH

This report has set forth two criteria depending upon the relative carcinogenicity of the compounds. These criteria, are:

Carcinogenic	$\leq$ 28 nanograms per liter
Noncarcinogens	$\leq$ 4 to 400 micrograms per liter

Each of these generalized classifications contain large numbers of specific organic chemicals. In order to determine the concentration of these compounds in a given water sample, and compare it to the criteria, a finite list of specific compounds must be selected for each classification. It is equally important to establish an analytical protocol for measuring the concentration, which can be used by different analysts and which will yield comparable analytical data. It is a requirement of the criteria that a specific protocol for sampling, extraction and analysis be followed. An analogy in establishing a site specific criteria is the promulgation of the national priority pollutant criteria by EPA. EPA defined very specific protocols for the laboratory testing, field sampling, quality assurance, etc. These protocols included specific finite tests of pollutants which were to be identified and quantitated as a requirement for satisfying the criteria. The currently available data on the site has been generated by several different methods. It is critical that prior to initiating a remedial action (treatment of a specific well) it be clear that the data has been generated in a consistant and reliable manner. Specifically it is necessary to insure that the water supply has been sampled and analyzed in a consistant and reliable manner and the results compared in a statistically significant way to a reasonable and defendable criteria.

In theory, if all combinations of alkyl substitution and ring joining are considered there are an infinite number of PAH compounds to select as criteria parameters. To make the task of monitoring a water source manageable, a finite list of compounds must be selected. A reasonable place to begin is with a list of compounds which can be detected by state-of-the-art analytical chemistry. This analytical

chemistry requirement includes availability of pure analytical standards, ability to sample and transport without substantial loss or degradation of the pollutant, and the ability to measure the pollutant at a level low enough to satisfy the criteria.

Much analytical work has been conducted on water samples from the St. Louis Park water system. Based on a review of this data, a list of approximately thirty-one PAH and heterocycles can be compiled. These compounds represent the typical PAH reported by EPA and WHO plus others known to originate in coal tar and coal tar derivatives. This list is shown by classification in Table J2-1 and is typical of the analyses conducted by Monsanto Research Corporation for Reilly Tar and Chemical.

The list represents those compounds which are likely to be present at St. Louis Park and which can be measured reliably by the analytical protocol (Section J7). Because of the wide range of compounds included and the analytical protocol being used, many other two to six ring PAH would also be detected if present. However, other PAH have not been detected routinely in past analyses. To include more compounds in this list merely increases the cost of analysis and lengthens a pollutant list which could be continually expanded. It is important to define specifically the compounds to be used in satisfying the criteria. This primary list represents those pollutants likely to contribute to the final concentration being considered by the criteria.

Tables 4-1 and 4-2 list all of the currently recognized carcinogenic PAH. In addition to the primary list of contaminants, which are the basis of the compliance monitoring standard, during periodic samplings, samples will be analyzed to include the broad range of carcinogens. Many of the compounds listed in Tables 4-1 and 4-2 are isomers and are not separately identifiable. Therefore, this secondary list will include specific carcinogenic PAH, where possible, and general isomeric groups of carcinogenic PAH (i.e., methylated acridines). The analytical method proposed in Section J7.4 can detect the presence of particular molecular weight PAH. By selecting representative compounds from each group of carcinogenic PAH, an analysis will be performed to verify that carcinogenic PAH compounds

TABLE J2-1

COMPLIANCE MONITORING STANDARD, PRIMARY COMPOUND LIST

Carcinogens	Non-Carcinogens and Others
Benz(a)anthracene	Indene
Dibenz(a,h)anthracene	2,3-dihydroindene
Benzo(b)fluoranthene	Naphthalene
Benzo(a)pyrene	2-methyl naphthalene
Quinoline	1-methyl naphthalene
Indeno (1,2,3,cd) pyrene	Biphenyl
Chrysene	Acenaphthylene
Benzo (g,h,i) perylene	Dihydroacenaphthylene
	Fluorene
	Phenanthrene
	Anthracene
	Fluoranthene
	Pyrene
	Benzo(k)fluoranthene
	Benzo(e)pyrene
	Perylene
	Acridine
	Carbazole
	2,3-benzofuran
	Dibenzofuran
	Benzo(b)thiophene
	Dibenzothiophene
	Indole

not included on the primary list are still not present in the source water. Any indication of the presence of a new compound will result in more specific analytical identification.

This analysis for the secondary list of contaminants will not be performed every sampling, but will be included at regular intervals as described in Section J4. The purpose of analyzing sources infrequently for the secondary list is to ensure that new contaminants are not entering the groundwater. Each time analytical data is generated for the secondary list, it will be reviewed to determine the presence of any significant levels of specific PAH not already included on the primary list. A significant level will be any measurable concentration above the lower detectable limit, using the method described in Section J7. If a compound is detected, it will be added to the primary list and included in the determination of total PAH on subsequent samplings.

The analytical data generated during the compliance monitoring will be reviewed and compiled after each sampling round. In addition, after the first five years of routine sampling, the data will be reviewed once each year to evaluate the compounds comprising the primary list. Any compound which has not been detected at the lower limit of detection, using the method in Section J7, for all samplings during the previous five years, will be removed from the primary list; but the compound will remain on the secondary list. The data generated from the infrequent sampling of the secondary list will be reviewed, as explained earlier, to determine whether any compound should be moved onto the primary list. After five years, once each year thereafter, this data will be reviewed, and any compound not detected at the lower detectable limit using the method in Section J7 will be removed from the secondary list. If any compound listed in Table J2-1 as a non-carcinogen is shown to be a carcinogen, it will be so changed on the primary list. Subsequent samplings will include compounds so identified in the calculation for total carcinogenic PAH. Newly identified carcinogenic PAH not on either the primary list or the secondary list will be placed on the secondary list for subsequent samplings to insure that the compound is not present in the source water.

J3. LOCATION OF SAMPLING POINTS AND WELL GROUPINGS

Either treated or untreated wellwater will be sampled at the point the water enters the distribution system. It is this sampling point which will be used to determine compliance with the criteria. If wells are treated, untreated water from the wellhead will also be sampled. This serves a threefold purpose. One, the data will be used to determine the type treatment required and to verify that the current treatment is still appropriate. Two, the data will be reviewed to insure that the assumptions used to select a control monitoring scheme (Appendix G) are still valid. Three, the data will demonstrate either that the quality of the raw water still necessitates treatment or that conditions have improved and treatment may be simplified or eliminated. Review of the data over time will allow early predictions of future adjustments to the treatment process.

As discussed in Section J2, individual PAH may be added to or deleted from the primary list, as water quality data dictates. For wells which depend upon treatment for PAH removal, this decision process will depend upon the data generated from the untreated well water. This same list of primary and secondary PAH will be applied to both the treated and untreated water from a given well. However, if a well is treated, compliance will be determined from the concentrations measured only in the treated water as is enters the distribution system.

A well will be monitored for criteria compliance if it falls within any one of three groups, summarized on Table J3-1. Group 1 includes wells which exceed the criteria, but are being treated (Group 1A) and wells whose PAH concentration exceeds the trigger value, as defined below, but do not exceed the criteria (Group 1B). Group 2 includes wells which exceed the criteria but are not currently in use (Group 2A) and wells below the trigger value but predicted to be in the path of contaminant migration and to become contaminated within about 10 years (Group 2B). Group 3 includes wells whose PAH concentration is below the trigger value, and may be within the path of predicted future migration, within the next 100 years.

TABLE J3-1

MONITORING WELL GROUPS AND SAMPLING FREQUENCIES

Group 1 Quarterly Sampling

A) Wells exceeding the criteria but being treated

B) Wells whose PAH concentration exceeds the trigger value but are below the criteria

Group 2 Yearly Sampling

A) Wells which exceed the criteria but are not being used

B) Wells below the trigger value but predicted to be in the path of future migration and to become contaminated within 10 years

Group 3 Sampling Every Five Years

Wells below the trigger value, in the path of possible future migration, but predicted not to become contaminated for at least 100 years.

The trigger value acts as an early warning that the levels of PAH in a well are nearing the compliance criteria. A well will be considered to exceed the trigger value if:

1) The sum of all carcinogenic PAH listed on the preimary list for that well equals or exceeds 5.0 parts per trillion.

- or -

2) The sum of all non-carconigenic PAH listed on the primary list for that well equals or exceeds ten percent of non-carcinogenic criteria.

As discussed in the following Section (J4) frequency of sampling will vary with the group in which the well is classified. Analytical data obtained for each well will be reviewed every five years to determine if each well is still in the appropriate group. The current groundwater quality is sufficiently stable to preclude more frequent review. This five year review will establish the groupings for the next five sampling years.

For wells in Groups 2 or 3, if the trigger value (as defined) has been exceeded during the previous five years, the affected well(s) will be added to Group 1. Wells may also be moved from Group 3 to Group 2 if contaminant migration proceeds. Wells will not be moved down in classification without comprehensive program review.

J4. FREQUENCY OF SAMPLING

As discussed in section J3, municipal drinking water wells are divided into three groups. Each group requires a different level of intensity for compliance monitoring. The major emphasis of the compliance monitoring is protection of the public health. Therefore, the groupings were selected based on that concern.

Group 1 represents the biggest risk to public health, for it includes wells known to be contaminated. Therefore, Group 1 wells require the most frequent monitoring, and will be sampled quarterly. Group 2 wells offer no current risk to public health, but possible future risk, and therefore, will be sampled yearly. As discussed in section J3, once the PAH concentration has increased above the trigger level, a well will be moved up to Group 1 and receive more frequent sampling. Until that point in time, yearly sampling offers adequate protection. Group 3 wells offer no current risk and improbable future risk to public health, and will be sampled every five years. The sampling for Group 3 wells will be spread over the five year period so that a portion of Group 3 wells are sampled each year.

In summary, the frequency of sampling will be as follows:

Group 1	quarterly
Group 2	yearly
Group 3	every five years

The frequency of sampling for each well in Groups 1 and 2 will be reviewed every five years. This review will be on an individual well basis. The analytical data generated during all samplings in the previous five year period will be statistically analyzed. If the analytical data does not vary significantly, as discussed below, the frequency of sampling may be decreased. Wells in Group 1 could go to semi-annual or annual sampling, and wells in Group 2 could go to sampling every two to five years. No wells will be sampled less than every five years.

Every fourth sampling, the secondary list will be analyzed in place of the primary list. Initially therefore, Group 1 wells will be

analyzed for the secondary list once each year, Group 2 once each 4 years, and Group 3 wells once each twenty years. As the normal frequency for each group lengthens, as discussed earlier, the frequency of secondary list analyses correspondingly lengthens. Secondary analyses will be performed on a rotating basis so that every year some wells are being checked.

The decision to change the frequency of sampling for a particular well will depend on the statistical consistency of that well's analytical data over the previous five year period. An appropriate statistical scheme must be developed, to accurately assess the degree of variability occurring in the monitoring of analytical data. The following considerations must be addressed:

- Statistical model must be applicable to a data base of the size and type operated by the compliance monitoring program.
- The statistical model should be specific to PAH, or accurately adaptable to PAH data.
- The statistical model should consider normal variations in ground-water sampling and analysis and account for them.
- The statistical model should consider normal fluctuations in ground-water aquifers and account for them.

Few data exist relative to statistical analysis of ground water. However, it is a subject of considerable interest and research at the present time. Likewise, very little statistical data is available on PAH sampling and analysis in water. The EPA is currently completing a round robin study of their Method 610 for PAH. That method is very similar to the analytical method recommended in Section J7. The report on the study will be available in mid-to-late 1983. That study coupled with emerging data on groundwater statistics will be used to develop a statistical model to define the acceptable variability of the analytical data generated during compliance monitoring.

J5. CALCULATION OF CRITERIA CONCENTRATION

Table J2-1 lists the compliance monitoring standard primary compounds by classification. To determine the criteria total concentration of PAH in each classification, the sum of all the PAH detected in that classification will be calculated. This total PAH value will be compared to the criteria allowable level for the respective classification.

For the purposes of determining the total concentration, PAH not detected at the lower detectable limit using the method described in section J7 will be assumed to be zero. Only those PAH shown on Table J2-1 for each classification will be used for the calculations. As described in section J2 the primary list may change with time as conditions at each source dictate. The compounds included in the total PAH calculation will be those on the primary list for that particular source for that particular sampling.

The recommended analytical method (Section J7) requires the use of surrogate spikes to verify extraction efficiency. It is recommended that the following compounds be used as surrogates:

Naphthalene, d_8
Fluorene, d_{10}
Chrysene, d_{12}

The list of surrogate compounds is representative of the molecular weight range of the PAH on the primary list. Surrogates are added to each water sample prior to beginning the analytical procedure. Therefore, each sample has a unique measurement of method efficiency. As discussed in Section J7.5 the data generated for surrogate recoveries for each sample must be compiled and statistically analyzed. Control limits must be defined for the laboratory and then used to determine the validity of sample data. As new guidelines are made avaiable by the EPA, the laboratory should compare its method efficiency to that reported and take approriate corrective action where discrepencies exist.

J6. ENFORCEMENT

The overriding concern of enforcement is the protection of the public health. In order to meet that concern an action plan is needed which, in the event that data from a routine compliance sampling round demonstrates exceedance of the standard, will initiate a systematic correction of the exceedance. Figure J6-1 shows the recommended decision tree in the event an exceedance is indicated.

The first step is to verify that an exceedance does exist. The source in question will be resampled in duplicate within ten (10) days after official receipt of data indicating exceedance. Following analysis of the duplicate samples, the data will be reviewed and a determinaton made as to whether upon resampling the average of the duplicates still indicates exceedance. If the duplicate data does indicate exceedance, the source is considered to be in exceedance of the criteria. If the duplicate data does not indicate exceedance, the source is sampled again, in duplicate, within 30 days of receipt of the first resample duplicate data. If the duplicate data from the third sampling does not exceed the criteria, the source returns to the normal compliance monitoring schedule. If the duplicate data from the third sampling exceeds the criteria, the source is in exceedance of the criteria.

Wells with treatment systems for PAH removal are unlikely to exceed the compliance standard. Routine control monitoring, used to insure proper treatment, should adequately warn of changes prior to exceeding the criteria. In the event that the control monitoring does not indicate a problem and routine compliance monitoring exceeds the criteria, the control monitoring technology will need thorough review. Water leaving the treatment system will be diverted to a sanitary or storm sewer until the problem has been solved. A complete study of the treatment system, and the control monitoring methodology, described in Appendix G will be instituted. Once the system is operating efficiently, three successive analyses, at one week intervals showing compliance with the criteria will be necessary prior to returning the treated water to the distribution system.

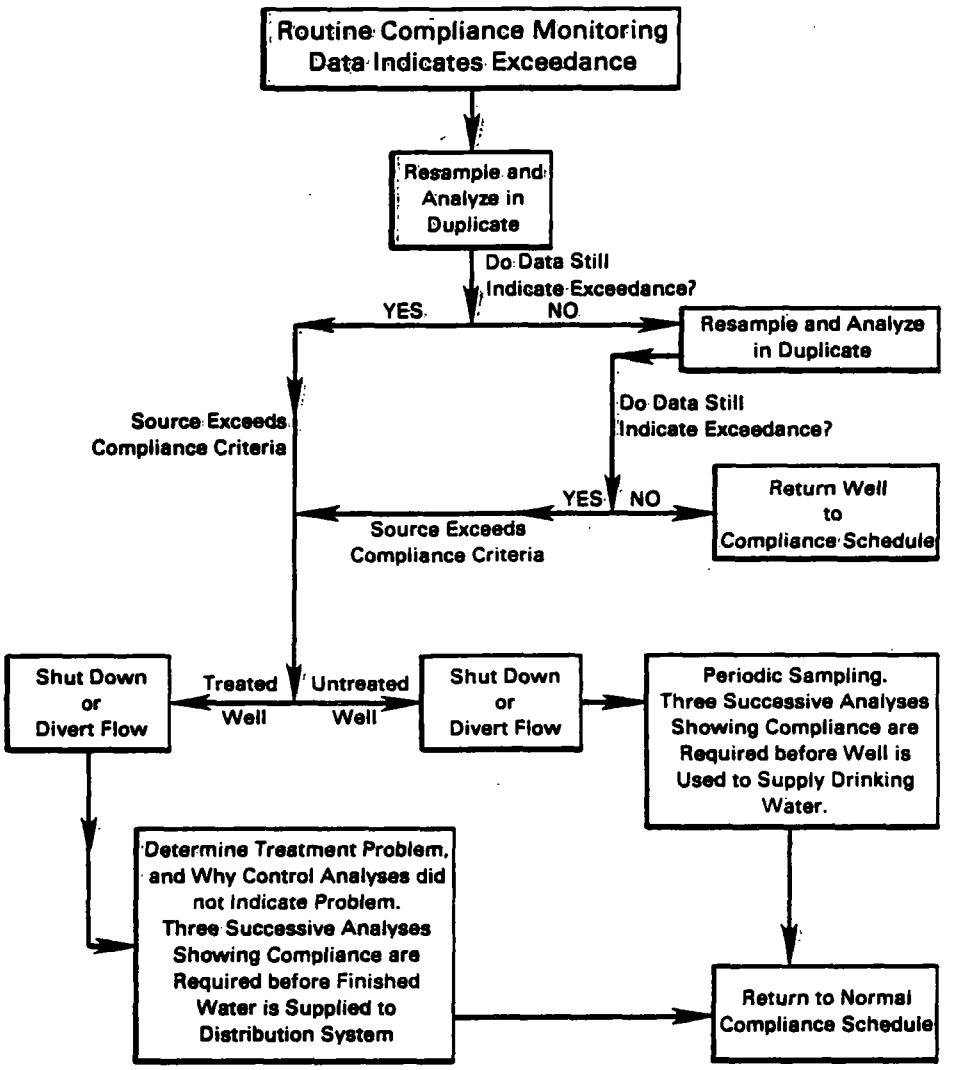

Figure J6-1 Enforcement Decision Tree

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If an untreated well is demonstrated to exceed the criteria, the well will be immediately shut down, or the water diverted to a sewer. Guidelines for determining how and when a well may be restarted, once it has exceeded the criteria are discussed in detail in Chapter 6 of this report.

J7. SAMPLING AND ANALYSIS METHODOLOGY

J7.1 General

There are four areas of concern to be considered when collecting a sample from a water source for the purposes of showing compliance with the established criteria.

- Sample control and chain of custody
- Sampling/sample preservation/storage
- Analysis
- Quality Assurance

Since compliance monitoring has legal implications, all samples taken for analysis must be traceable throughout the sampling and analysis process. This can only be achieved through close attention to the labelling, handling, transport, and storage of the samples. A major consideration in determining whether or not a water source meets the established criteria is the care taken and methods followed for the sampling and analysis. The sampling protocol is a critical factor in assuring that the sample analyzed in the laboratory is representative of the water source. Because of the variability of different analytical methods, when a criteria contaminant concentration is selected, it must be related to the exact analytical procedure used to develop the criteria. In this way, any analyst who is submitting data on a water source, knows that having used a specific analytical protocol, his data can be compared fairly to the criteria concentration. It also acts as a safeguard, insuring that any data submitted to the regulatory agency has been developed in a prescribed and uniform manner. Finally, the quality assurance program provides evidence that the analytical data being submitted not only was generated using an appropriate method, but that the analyst performed the method adequately.

J7.2 Sample Control Procedures and Chain of Custody

The successful implementation of a monitoring program depends on the capability to produce valid data and to demonstrate such validity. In addition to proper sample collection, preservation, storage and handling, appropriate sample identification procedures and chain of custody are necessary to help insure the validity of the data. The procedures specified herein are those used by the Office of Enforcement, U.S. Environmental Protection Agency as of October, 1980. However, changes may occur and the reader is advised to keep abreast of official uniform procedures.

A sample is physical evidence collected from a facility or from the environment. An essential part of all compliance investigations is that evidence gathered be controlled. To accomplish this, the following sample identification and chain-of-custody procedures are recommended.

J7.2.1 Sample Identification

The method of identification of a sample depends on the type of measurement or analyses performed. When in-situ measurements are made, the data are recorded directly in logbooks with identifying information (project code, station numbers, station location, date, time, samplers), field observations, and remarks. Examples of in-situ measurements are pH, temperature, conductivity, and flow measurement.

Samples other than in-situ measurements, are identified by a sample tag or label (hereinafter referred to as sample tag).

These samples are transported from the sample location to a laboratory or other location for analysis. Sample tags shall be completed for each sample, using waterproof ink, unless prohibited by weather conditions. For example, a logbook notation would explain that a pencil was used to fill out the sample tag because a ballpoint pen would not function in freezing weather. The information recorded on the sample tag includes:

Station Location - Description of place where sample was taken.

Date - A six-digit number indicating the year, month and day of collection

Time - A four-digit number indicating the military time of collection

Preservation - Type of preservation added in the field, if any.

Sampler - Signature of person collecting the sample.

Remarks - Any pertinent observations or further sample description.

After collection, identification, and preservation, the sample is maintained under chain-of-custody procedures discussed below.

J7.2.2 Chain-of-Custody Procedures

Due to the evidentiary nature of samples collected during compliance investigations, possession must be traceable from the time the samples are collected until they are introduced as evidence in legal proceedings. To maintain and document sample possession, chain-of-custody procedures are followed. A sample is under costody if:

1. It is in your possession, or
2. It is in your view, after being in your possession, or
3. It was in your possession and then you locked it up to prevent tampering, or
4. It is in a designated secure area

J7.2.2.1 Field Custody Procedures

1. In collecting samples for evidence, collect only that number which provides a good representation of the media being sampled. To the extent possible, the quantity and types of samples and sample locations are determined prior to the actual field work. As few people as possible should handle samples.

2. The field sampler is personally responsible for the care and custody of the samples collected until they are transferred or dispatched properly.
3. The sampling supervisor determines whether proper custody procedures were followed during the field work and decides if additional samples are required.

J7.2.2.2 Transfer of Custody and Shipment

1. Samples are accompanied by a Chain-of-Custody Record. When transferring the possession of samples, the individuals relinquishing and receiving will sign, date, and note the time on the record. This record documents sample custody transfer from the sampler, often through another person, to the analyst at the laboratory.
2. Samples will be packaged properly for shipment and dispatched to the appropriate laboratory for analysis, with a separate custody record accompanying each shipment. Shipping containers will be padlocked or sealed for shipment to the laboratory. The method of shipment, courier name(s) and other pertinent information are entered in the "Remarks" box.
3. Whenever samples are split with a another laboratory, it is noted in the "Remarks" section. The note indicates with whom the samples are being split and is signed by both the sampler and recipient. If either party refuses a split sample, this will be noted and signed by both parties. The person relinquishing the samples to the facility or agency should request the signature of a representative of the appropriate party, acknowledging receipt of the samples. If a representative is unavailable or refuses to sign, this is noted in the "Remarks" space. When appropriate, as in the case where the representative is unavailable, the custody record should contain a statement that the samples were delivered to the designated location at the designated time.

4. All shipments will be accompanied by the Chain-of-Custody Record identifying its contents. The original record will accompany the shipment, and a copy will be retained by the sampling supervisor.

J7.2.3 Field Forms

In addition to sample tags and chain-of-custody forms, a bound field notebook must be maintained by the sample team leader to provide a daily record of significant events. All entries must be signed and dated. All members of the of the sampling team must use this notebook. Keep the notebook as a permanent record.

J7.3 Sampling/Sample Preservation/Storage

The importance of proper sampling of wells cannot be over-emphasized. Even though the well being sampled may be correctly located and constructed, special precautions must be taken to ensure that the sample taken from that well is representative of the ground water at that location and that the sample is neither altered nor contaminated by the sampling and handling procedure.

When sampling finished water from a treatment system, the sampling point chosen must insure that a well-mixed representative sample of the water actually being fed into the distribution system is collected.

J7.3.1 Representative Samples

Samples should be taken from permanent sampling taps installed in the main feed line from the well head or the representative discharge line from the treatment plant. When sampling the treatment plant discharge line, the main concern is that the water in the sampling tap and associated pipes has been flushed and replaced with water from the mainflow. This is accomplished by allowing the tap to run for 1-2 minutes prior to sampling. Ideally taps should be installed on or as close to the discharge line as possible. However,

in some cases, it may be necessary to run longer lengths of pipe in order to locate the sample tap in a convenient location. The amount of pre-sample flushing will depend upon the amount of piping involved.

Samples from wells should be collected from taps installed on the main feed line at the wellhead. Normally, wells are pumped for a sufficient length of time to remove a volume of water equivalent to four to ten bore volumes. However, the time-series study performed by ERT in December, 1982 and discussed in section G4.4.6, indicates that a longer period of pumping is required before equillibrium is reached in the aquifer. Based on that work, it is recommended that a well be pumped a minimum of twelve hours prior to sampling. At the time of sampling, the sampling tap should be flushed for one to two minutes.

For any PAH sampling event, be sure that the sample tap is clean, and the general sampling area is free from excessive dust, fumes, or chemicals.

J7.3.2 Sample Containers

Only amber 1 liter glass bottles should be used. Caps should be fitted with pre-cleaned Teflon liners. Four bottles are required for each sample collected.

Bottles should be prepared as follows:

1. Wash bottles with hot detergent water.
2. Rinse thoroughly with tap water followed by three or more rinses with organic-free water.
3. Rinse with Burdick & Jackson quality redistilled acetone, followed by equivalent quality methylene chloride.
4. Allow to air dry in a contaminant free area.
5. Caps and liners must be washed and rinsed also.

Bottles should be stored and shipped with the Teflon-lined caps securely fastened.

J7.3.3 Sample Collection

Samples are collected from the sample tap by filling each of the four amber bottles in rapid succession. Do not prerinse the bottles with sample. Hold the bottle under the sample stream without allowing the mouth of the bottle to come in contact with the tap. Fill the bottle completely, and securely tighten the cap. Be sure all sample labels are completed, as well as sample custody forms and a description of the sampling event recorded in the field notebook.

J7.3.4 Sample Preservation, Shipment, and Storage

The samples must be iced or refrigerated at 4°C from the time of collection until extraction. PAH's are known to be light sensitive, therefore, samples, extracts and standards should be stored in amber bottles and kept away from prolonged exposure to light. If residual chlorine is known or suspected to be present, add 80 mg of sodium thiosulfate per liter of sample. All samples must be extracted within seven days, and analysis completed within forty days.

Samples should be shipped in styrofoam sample boxes, if possible. If not, they should be protected from breakage and shipped in coolers. Blue ice should be used to maintain a temperature of 4°C. A carrier should be selected which will insure delivery at the laboratory within 24-36 hours after collection. For out-of-town shipment of samples, air express overnight service is recommended.

Samples received at the laboratory must be checked for leakage and a notation made regarding sample temperature at time of receipt. All samples should be stored in an organic-free refrigerator at 4°C. Storage refrigerators should be kept locked to prevent unauthorized entry and to satisfy chain-of-custody requirements.

J7.4 Analysis for Low-Level PAH in Water

J7.4.1 Scope and Application

This method covers the determination of a number of PAH and heterocycles that are partitioned into an organic solvent and are amenable to gas chromatography. The parameters listed in Table J2-1 may be quantitatively determined using this method.

This method is restricted to use by or under the supervision of analysts experienced in the oepration of gas chromatograph/mass spectrometers and skilled in the interpretation of mass spectra. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described.

J7.4.2 Summary of Method

Four 1-liter volumes of sample are extracted by seperating into two 2-liter samples and combining these two extracts. Analysis on the concentrated extract is performed by gas chromatography/mass spectroscopy using the selected ion monitoring mode.

J7.4.3 Interferences

Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing hardware that lead to discrete artifacts and/or elevated baselines in the total ion current profiles. All of these materials must be routinely demonstrated to be free from interferences under the conditions of the analysis by running laboratory reagent blanks.

Glassware must be scrupulously cleaned. Clean all glassware as soon as possible after use by rinsing with the last solvent used in it. This should be followed by detergent washing with hot water, and rinses with tap water and reagent water. It should then be drained dry, and heated in a muffle furnace at 400°C for 15 to 30 minutes. Solvent rinses with acetone and pesticide quality hexane may be substituted for the muffle furnace heating. Volumetric ware should

not be heated in a muffle furnace. After drying and cooling, glassware should be sealed and stored in a clean environment to prevent any accumulation of dust or other contaminants. Store it inverted or capped with aluminum foil. The use of high purity reagents and solvents helps to minimize interference problems. Purification of solvents by distillation in all-glass systems may be required.

Matrix interferences may be caused by contaminants that are coextracted from the sample. The extent of matrix interferences will vary considerably from source to source, depending upon the nature of the municipality being sampled.

J7.4.4 Apparatus

J7.4.4.1 Glassware

a) Separatory funnel - 4000 ml, with Teflon stopcock.
b) Concentrator tube, Kuderna-Danish - 10 ml, graduated (Kontes K-570050-1025 or equivalent). Calibration must be checked at the volumes employed in the test. Ground glass stopper is used to prevent evaporation of extracts.
c) Evaporative flask, Kuderna-Danish - 500 ml (Kontes K-570001-0500 or equivalent). Attach to concentrator tube with springs.
d) Snyder column, Kuderna-Danish - Three-ball macro (Kontes K-503000-0121 or equivalent).
e) Snyder column, Kuderna-Danish - Two-ball micro (Kontes K-569001-0219 or equivalent).

J7.4.4.2 Gas Chromatograph

An analytical system complete with a temperature programmable gas chromatograph and all required accessories including syringes, analytical columns, and gases. The injection port must be designed for on-column injection when using packed columns and for splitless injection when using capillary columns.

J7.4.4.3 Column

A J&W wide-bore 30-meter fused silica capillary column coated with DB-5 bonded phase, or equivalent.

J7.4.4.4 Mass Spectrometer

A mass spectrometer utilizing a 70 volt (nominal) electron energy in the electron impact ionization mode and producing a mass spectrum which meets all the criteria when 50 ng of decafluorotriphenyl phosphine (DFTPP; bis(perfluorophenyl) phenyl phosphine) is injected through the GC inlet. Any GC to MS interface that gives acceptable calibration points for each compound of interest in Tables J2-1 and achieves all acceptable performance criteria may be used. GC to MS interfaces constructed of all glass or glass lined materials are recommended. Glass can be deactivated by silanizing with dichlorodimethylsilane.

A computer system must be interfaced to the mass spectrometer that allows the continuous acquisition and storage on machine readable media of all mass spectra obtained throughout the duration of the chromatographic program. The computer must have software that allows searching any GC/MS data file for ions of a specific mass and plotting such ion abundances versus time or scan number. The computer must allow aquisition at pre-selected mass windows for selected ion monitoring.

J7.4.5 Reagents

a) Reagent water - Reagent water is defined as a water in which an interferent is not observed at the method detection limit of each parameter of interest.
b) Acetone, methanol, methylene chloride - Pesticide quality or equivalent.
c) Sodium sulfate - (ACS) Granular, anhydrous. Purify by heating at 400°C for 4 hrs. in a shallow tray.

d) Surrogate Spiking Solution - A solution of 200 ng/ml of fluorene-d10, naphthalene-d8 and chrysene-d12 is prepared by weighing appropriate aliquots of the purified crystals into a volumetric flask and diluting to volume with methanol or acetone.

e) Internal Standard Solution - A solution of 100 ug/ml of anthracene-d10 is prepared by weighing an appropriate aliquot of the purified crystal into a volumetric flask and diluting to volume with methylene chloride.

J7.4.6 Calibration

The mass spectrometer response for all PAH, relative to anthracene-d10 internal standard is determined daily from the analysis of a PAH standard containing 1 ug/ml each PAH. Alternatively, a PAH in the sample may be calculated assuming the same total ion response of the closest eluting PAH in the standard.

J7.4.7 Extraction

Samples are extracted as received with no pH adjustment. Each 4-liter sample is separated into two 2-liter aliquots in two 4-liter separatory funnels. Each 2-liter aliquote is spiked in the separatory funnel with 200 ng each of naphthalene-d8, fluorene-d10, and chrysene-d12 using the surrogate spiking solution. Each aliquot is then extracted three times (90 ml/60 ml/60 ml) with methylene chloride. The three methylene chloride extracts are passed through an anhydrous sodium sulfate drying column, and combined in a Kuderna-Danish evaporative concentrator. The extracts are concentated to a volume of 1.0 ml. The extract from each of the two aliquots of the 4-liter sample are combined and further reduced to 1.0 ml.

J7.4.8 Daily GC/MS Performance Tests

At the beginning of each day that analyses are to be performed, the GC/MS system must be checked to see that acceptable performance criteria are achieved for DFTPP. These DFTPP performance test require the following instrumental parameters.

Electron Energy 70 volts (nominal)
Mass Range - 35 to 450 amu
Scan Time - to give at least 5 scans per peak but not to exceed 7 seconds per scan.

At the beginning of each day, inject 2 µL (50 ng) of DFTPP standard solution. Obtain a back-ground corrected mass spectra of DFTPP anc check that all the key ion criteria in Table J7-1 are achieved. If all the criteria are not achieved, the analyst must retune the mass pectometer and repeat the test until all criteria are achieved. The performance criteria must be achieved before any samples, blanks, or standards are analyzed.

J7.4.9 Gas Chromatography/Mass Spectroscopy

Just prior to analysis, 150 ul of sample is combined with 150 ul of a 100 ug/ml anthracene-d10 internal standard solution. Representative aliquots are injected onto the capillary column of the gas chromatograph using the following conditons:

Injector Temp -	250°C
Transfer Line Temp -	250°C
Initial Oven Temp -	50°C
Initial Hold Time -	4 min.
Ramp Rate -	8°C/min.
Final Temperature -	300°C

TABLE J7-1

DFTPP ABUNDANCE CRITERIA

Mass	Ion Abundance Criteria
51	30-60% of mass 198
68	less than 2% of mass 69
70	less than 2% of mass 69
127	40-60% of mass 198
197	less than 1% of mass 198
198	base peak, 100%
199	5-9% of mass 198
275	10-30% of mass 198
365	greater than 1% of mass 198
441	preent but less than mass 443
442	greater than 40% of mass 198
443	17-23% of mass 442

The effluent from the GC is fed into the ion source of the mass spectrometer. The MS is operated in the selected ion monitoring mode using appropriate windows to include the masses of each PAH as shown in Table J7-2.

J7.4.10 Calculations

The following formula is used to calculate the response factors of the internal standard to each of the calibration standards.

$$RF = (A_s C_{is})/(A_{is} C_s)$$

where:

A_s = Area of the characteristic ion for the parameter to be measured.

A_{is} = Area of the characteristic ion for the internal standard.

C_{is} = Concentration of the internal standard, (µg/L).

C_s = Concentration of the parameter to be measured, (µg/L).

Based on these response factors, updated daily sample concentration for each PAH is calculated using the following formula.

$$\text{Concentration, ng/l} = \frac{(A_s)(I_s)}{(A_{is})(RF)(V_o)}$$

where:

A_s = Area of the characteristic ion for the parameter to be measured.

A_{is} = Area of the characteristic ion for the internal standard.

I_s = Amount of internal standard added to each extract (µg).

V_o = Volume of water extracted (liters).

TABLE J7-2

COMPOUNDS AND MS QUANTITATION MASS IONS

Dihydroacenaphthylene Compound	Quantitation Mass Ion Quantitation Mass Ion
Indene	116
2,3-Dihydroindene	118
Naphthalene	128
2-Methylnaphthalene	141
1-Methylnaphthalne	141
Biphenyl	154
Acenaphthylene	152
Dihydroacenaphthylene	154
Fluorene	166
Phenanthrene	178
Anthracene	178
Fluoranthene	202
Pyrene	202
Benzo(a)anthracene	228
Chrsene	228
Benzo(b)fluoranthene	252
Benzo(k)fluoranthene	252
Benzo(e)pyrene	252
Benzo(a)pyrene	252
Perylene	252
Indeno(1,2,3,cd)pyrene	276
Dibenz(a,h)anthracene	278
Benzo(g,h,i)perylene	276
Acridine	178
Carbazole	166
2,3-benzofuran	*
Dibenzofuran	*
Benzo(b)thiophene	*
Dibenzothiophene	*
Quinoline	*
Indole	*

*Not determined at this time.

J7.5 Quality Assurance

Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and the analysis of spiked samples as a continuing check on performance. The laboratory is required to maintain performance records to define the quality of data that is generated. Before performing any analyses, the analyst must demonstrate the ability to generate acceptable accuracy and precision with this method. The laboratory must spike all samples with surrogate standards to monitor continuing laboratory performance.

To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

a) For each parameter to be measured, select a spike concentration representative of the expected levels in the samples. Using stock standards, prepare a quality control check sample concentrate in acetone 1000 times more concentrated than the selected concentrations. Quality control check sample concentrates, appropriate for use with this method, are available from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268.

b) Using a pipet, add 1.00 ML of the check sample concentrate and 1.0 mL of the surrogate standard dosing solution to each of a minimum of four 100-mL aliquots of reagent water. Analyze the aliquots according to the method.

c) Calculate the average percent recovery, (R), and the standard deviation of the percent recovery (s), for all parameters and surrogate standards. Wastewater background corrections must be made before R and s calculations are performed.

Using this surrogate standard data, generate a control chart using the values for R and s. The upper control limit (UCL) and lower control limit (LCL) are defined as R+3s and R-3s respectively. Data for surrogate recoveries for each sample analyzed should be added to the control chart. The control chart should be used as a guide in observing trends in the efficiency of the method. Once sufficient data has been entered onto the chart (at least 20 data points), set actual control limits which can be used to determine the validity of each sample. These control limits should be updated periodically, and compared to EPA data which may become available. Significant variation from published efficiency data should prompt corrective action.

The laboratory is required to spike all samples with the surrogate standard spiking solution to monitor spike recoveries. If the recovery for any surrogate standard does not fall within control limits for method performance, the results reported for that sample must be qualified. The laboratory should monitor the frequency of data so qualified to ensure that it remains at or below 5%.

Before processing any samples, the analyst should demonstrate through the analysis of a one-liter aliquot of reagent water, that all glassware and reagents interferences are under control. Each time a set of samples is extracted or there is a change in reagents, a laboratory reagent blank should be processed as a safeguard against laboratory contamination.

It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to monitor the precision of the sampling technique. Whenever possible, the laboratory should perform analysis of standard reference materials and participate in relevant performance evaluation studies.

J8. COST FOR MONITORING MUNICIPAL SUPPLY WELLS

This section presents estimated costs for monitoring municipal supply wells, based on the sampling and analysis procedures recommended in this appendix and the predicted contaminant migration discussed in Chapter 6 and Appendix E. The three key factors required to estimate the total present value cost of monitoring municipal supply wells are (1) estimating costs for individual sample analyses, (2) categorizing municipal supply wells by the sampling frequency groups discussed in section J4, and (3) estimating how the required sampling frequencies for municipal supply wells will change as contaminants migrate in the future. Each of these factors are discussed below.

J8.1 Analytical Costs

The estimated cost for an SIM GC/MS analysis of the primary list of PAH and heterocyclic PAH is from $500 to $600 per sample. This includes the cost of internal laboratory quality control procedures. The estimated cost for a GC/MS analyses for the secondary list of PAH and heterocyclic PAH is from $1000 to $1500 per sample, again including laboratory quality control costs. The estimated cost range is wider for the secondary list analysis because of uncertainties in the number of compounds requiring identification and quantification.

Table J8-1 shows the total present value cost of analyzing samples from a single well collected quarterly, annually or every five years. The total present value cost includes an additional 20% for analyzing field blanks and replicate samples. Costs for analyses which occur less than once a year are expressed on an average annual basis. This reflects the assumption that such analyses will be staggered for a group of wells, resulting in some analyses being performed every year.

TABLE J8-1

ESTIMATED PRESENT VALUE COST FOR MONITORING A SINGLE MUNICIPAL SUPPLY WELL AT VARIOUS FREQUENCIES

Monitoring Frequency	Analytical Cost, $ Per Year		Present Value Cost $Thousands
	Primary List	Secondary List[a]	
Quarterly	2000-2400	1000-1500	72-93
Annually	500-600	250-375	18-23
Every 5 Years[b]	100-120	50-75	3.6-4.6

NOTES:

[a] Once every four samples.

[b] Average annual cost, even though analysis is done once very five years.

[c] Based on 100 years at 5 percent effective annual interest rate. Includes an additional 20 percent for field blanks and replicate samples.

J8.2 Initial Sampling Frequency Groupings

Table J8-2 presents the recommended initial categorization of municipal supply wells in the St. Louis Park area into the different recommended sampling frequency groupings. All municipal supply wells in St. Louis Park and Hopkins are covered including the new Mt. Simon-Hinckley well in St. Louis Park (well SLP17), plus most of the Praire du Chien-Jordan wells in Edina. Wells are categorized according to the results of PAH analyses performed to date (as summarized in Appendix K) and the predicted migration of PAH contaminants (as discussed in Chapter 6, Section 6.2). Wells are categorized for best case contaminant migration based on currently observed PAH concentrations. Wells are similarly categorized for worst-case contaminant migration, except for the assumption that well SLP4 will exceed the recommended PAH criteria soon after being placed in service and that SLP6 will soon follow (see Chapter 6, Section 6.2).

Table J8-2 shows well sampling groupings for three different combinations of 1) a criterion for noncarcinogenic PAH and heterocyclic PAH and 2) end-use controls. The first case is based on a noncarcinogen criterion at the high end of the recommended range (500 micrograms per liter), in which case no end-use controls are required (see Chapter 6, Section 6.2). The second and third cases are based on a noncarcinogen criterion at the low end of the recommended range (4 micrograms per liter) with drinking water treatment and new Mt. Simon-Hinckley supply wells as the end-use controls, respectively. These latter two cases differ slightly in the categorization of wells SLP6, SLP10 and SLP15, based on whether these wells are treated or replaced. Well groupings for the high noncarcinogen criterion case involve less frequent monitoring for most wells, compared to the low criterion cases. This is because no municipal supply wells currently exceed the high criterion, and no wells are currently above the trigger level corresponding to the high criterion. Furthermore, significant migration of contaminants at concentrations approaching the high noncarcinogen criterion is not expected (see Chapter 6, Section 6.2).

RECOMMENDED INITIAL GROUPING OF MUNICIPAL SUPPLY WELLS FOR PAH MONITORING

Group Number and Monitoring Frequency	Well Identities for Different Noncarcinogen Criteria and End-Use Controls: 400 Micrograms Per Liter Criterion	4 Micrograms per Liter with Drinking Water Treatment	4 Micrograms per Liter with New Mt.-Simon-Hinckley Wells
Best Case Contaminant Migration			
1. Quarterly			
1A. Being treated[a]	None	SLP10,15	None
1B. Exceed Trigger Level	SLP5,10,15[d]	SLP4	SLP4
2. Annually			
2A Exceeds Criteria	None	SLP5	SLP5,10,15
2B In Migration Path	SLP4,6,7,9; H3	SLP3,6,7,9,11,12,14,16,17; H3	SLP3,6,7,9,11,12,14,16,17; H3
3. Every Five Years	SLP3,8,11,12,13,14,16,17 H1,4,5,6 E2,3,4,6,7,13,15	SLP8,13[c] H1,4,5,6 E2,3,4,6,7,13,15	SLP8,13[c] H1,4,5,6 E2,3,4,6,7,13,15
Worst Case Contaminant Migration			
1. Quarterly			
1A. Being Treated[a]	Same As Above	SLP6,10,15	None
1B. Exceed Trigger Level	Same As Above	None	None
2. Annually			
2A. Exceeds Criteria	Same as Above	SLP4,5	SLP4,5,6,10,15
2B. In Migration Path	Same As Above	SLP3,6,7,9,11,12,14,16,17; H3; E2,3,4,6	SLP3,6,7,9,11,12,14,16,17,18[b]; H3; E2,3,4,6
3. Every Five Years	Same As Above	SLP8,13[c]; H1,4,5,6; E7,13,15	SLP8,13[c]; H1,4,5,6; E7,13,15

NOTES:

(a) Wells being treated require two samples, one of untreated water and one of finished water. Single samples of untreated and treated water are adequate for wells SLP10 and 15 in combination (i.e., two samples total, not four) because these wells will be treated together.

(b) Well SLP18 represents a new Mt. Simon-Hinckley well in addition to SLP17, which is currently nearing completion.

(c) All St. Louis Park wells except SLP8 and SLP13 are recommended for annual monitoring, at least initially. SLP8 and SLP13 are recommended for monitoring every five years because there are other wells between them and the site (SLP16 and SLP11, respectively).

(d) None of these wells currently exceed 50 micrograms per liter, which would be the 10% trigger value. However to be conservative they are included in the costs.

J8.3 Future Sampling Frequency Groupings

Predicting future changes in sampling frequency groupings for municipal supply wells is very uncertain, given uncertainties in contmainant migration rates, directions and concentration. In spite of these uncertainties, an attempt is made to make these predictions in order to bound the likely present value cost of monitoring municipal supply wells. The predictions represent judgements based on the discussion of contaminant migration presented in Section 6.2 of Chapter 6 and the results of PAH analyses to date, as presented in Appendix K and Chapter 4. The predictions are judged to be conservative, since no allowance is made for attenuation of contaminants, particularly high molecular weight PAH, and because regular monitoring is assumed for municipal supply wells in St. Louis Park, Hopkins and Edina that should never be affected by PAH contaminants migrating from currently contaminated wells.

Table J8-3 summarizes the predicted changes to municipal supply well sampling frequency groupings over the next 100 years by showing the number of wells in each group for various future time periods. The time periods chosen are approximate and are based on the discussion of contaminant migration presented in Section 6.2 of Chapter 6. The number of wells in each frequency group was estimated by starting with the initial groupings in Table J8-2 and adjusting these groupings based on the predicted migration of contaminants and the particular combination of noncarcinogen criteria and end-use controls involved. The footnotes to Table J8-3 describe how the initial groupings were adjusted.

Table J8-3 does not categorize any wells for quarterly monitoring in the future, except for wells requiring drinking water treatment. This is because even rough predictions of when wells would exceed the trigger levels and subsequently exceed the criteria (i.e., when and for how long wells would require monitoring because PAH concentrations are between the trigger levels and the criteria) can not be made with any reasonable certainty.

TABLE J8-3

CURRENT AND PREDICTED MONITORING FREQUENCIES

FOR MUNICIPAL SUPPLY WELLS

Monitoring Frequenty	Total Number of Wells in Each Category For Different Noncarcinogen Criteria and End-Use Controls: 400 Micrograms Per Liter	4 Micrograms Per Liter With Drinking Water Treatment	4 Micrograms per Liter With New Mt. Simon-Hinckley Wells
Best Case Migration			
1983-1993[a]			
Quarterly	3	3	1
Annually	5	11	13
Every 5 Years	19	13	13
1993-ca.2033			
Quarterly	0	4(d)	0(d)
Annually	8(b)	16(d)	20(d)
Every 5 Years	19(c)	9(d)	9(d)
ca.2033-2083			
Quarterly	0	6(e)	0
Annually	8	17(f)	22(h)
Every 5 Years	19	12(g)	10(j)
Worst Case Migration			
1983-2003(a)			
Quarterly	3	4	0
Annually	5	16	20
Every 5 Years	19	9	9
2003-ca.2033			
Quarterly	0	6(e)	0
Annually	8(b)	17(f)	21(i)
Every 5 Years	19(c)	12(g)	19(j)
ca.2033-2083			
Quarterly	0	6	0
Annually	8	17	22(i)
Every 5 Years	19	12	10

NOTES:

(a)Initial well groupings from Table J8-2.

(b)Quarterly wells reduced to annual basis, assuming that steady concentrations will be attained above the trigger level.

(c)Same as initial groupings.

(d)Same as initial grouping for worts-case migration.

(e)Well E2 added to quarterly monitoring for a well being treated (requiring untreated and treated samples).

(f)Well E2 deleted and E7, 15, 17 added to previous grouping.

(g)Wells E7 and E15 deleted; wells E5, 8, 11, 16 and 18 added to previous grouping.

(h)Two new Mt. Simon-Hinckley wells in Edina added to previous grouping.

(i)One new Mt. Simon-Hinckley well in Edina added to previous grouping.

(j)Well E17 added to previous grouping.

J8.4 Total Present Value Costs

Table J8-4 shows the estimated total present value costs for compliance monitoring of municipal supply wells for the various cases of contaminant migration, noncarcinogen criteria, and end-use controls. These costs are derived from the predicted number of wells in the different sampling frequency groups shown in Table J8-3 and the present value costs for analyzing single wells shown in Table J8-1.

TABLE J8-4

ESTIMATED PRESENT VALUE COST FOR

MONITORING MUNICIPAL SUPPLY WELLS

Noncarcinogen Criteria and End-Use Controls Used	Present Value Cost, Thousands	
	Best Case Migration	Worst Case Migration
500 micrograms per liter noncarcinogen criterion	280-350	320-400
4 micrograms per liter noncarcinogen criterion		
• with drinking water treatment	560-720	670-860
• with new Mt. Simon-Hinckley wells	380-480	400-510

APPENDIX K

GROUND WATER QUALITY

DATA BASE

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K1. INTRODUCTION

Over the last five years, wells in St. Louis Park and the surrounding communities have been sampled extensively. To facilitate evaluation and comparison of the collected data, results of sample analyses for PAH, phenolics and other compounds have been compiled and entered into a computerized data base. Although its primary purpose is storage of ground-water data, the data base is also used for storage of analytical data from treated water samples and surface water samples.

K2. GROUND-WATER DATA BASE STRUCTURE

Each ground-water sample in the data base is identified by well, sample date and sample number. The associated laboratory and analytical method are identified, and a report ID and page number are included to document the data source. Well depth, well location and the aquifer(s) open to the well bore are also entered for each ground-water sample.

Individual compounds included in the data base are listed in Table K2-1. Entries are also provided for phenolics and benzene extractables. When a sample has been analyzed for a compound that is not explicitly included in the data base, the analysis results are noted in a comment field provided for each sample.

K3. PAH COMPOUND DATA BASE

All PAH and related compounds in the ground-water data base are cross referenced to another computerized data base that stores Chemical Abstracts registration number, CAS name, molecular formula and various physical property data for each compound. Table K3-1 presents this information, including available boiling point, melting point and solubility data. An illustration of the compound structure is also included.

Compounds in Table K3-1 are listed in alphabetical order* by the name with which the compound is identified in this report. Many PAH have several names associated with them; therefore, all known synonyms are also listed.

Several of the compounds in Table K3-1 actually represent a group of individual compounds. For example, a single generic structure represents all twelve isomers of methylbenz(a)anthracene (i.e., 1-methylbenz(a)anthracene through 12-methylbenz(a)anthracene). The precise structure of each isomer may be derived by following PAH nomenclature rules.

K3.1 PAH Nomenclature

IUPAC (International Union of Pure and Applied Chemistry) has recently attempted to systematize PAH nomenclature. For more than a century, many of the basic ring groups have been named unsystematically; names may reflect the initial isolation of the compound from coal tar (e.g., naphthalene, pyrene), its color (e.g., fluoranthene) or its shape (e.g., coronene). Due to their wide use, these names have been retained in the IUPAC system. More complex compounds are identified by prefixing the names of other component parts to the name of the parent ring system (e.g., benzo(a)pyrene, dibenzo(a,h)anthracene). The following list of rules determines the orientation from which compounds are numbered (Lee, et. al. 1981, Pucknat 1981).

- As many rings as possible are drawn in a horizontal line, with two sides vertical wherever possible.

- As much of the molecular structure as possible is arranged in the upper right quadrant, with as little as possible in the lower left quadrant (the middle of the first row is taken as the center of the 'circle').

*Exceptions are linked compounds, such as biphenyl, which are included at the end of the table.

- Beginning in the most right-hand ring of the top row, the first carbon atom in the parent compound not engaged in ring fusion is number 1. Numbering of single-ring carbon atoms proceeds clockwise around the molecule (exceptions: anthracene and phenanthrene).

- Letters are assigned in alphabetical order to faces of rings, beginning with 'a' for the side between carbon atoms 1 and 2 and proceeding clockwise around the molecule; ring faces shared by two rings in the parent compound are not lettered. For example, benzo(a)pyrene consists of a benzene ring fused to the 'a' bond of the parent pyrene structure.

- Hydrogenated compounds are indicated by prefixes such as dihydro, hydro, etc. followed by the name of the unreduced hydrocarbon, (e.g., 1, 4 - dihydronaphthalene).

Similar rules apply when naming and numbering heterocyclic analogs and derivatives of PAH. In general, the compound name consists of a hydrocarbon ring system followed by a trivial heterocycle name. In an alternative IUPAC-approved system, heterocyclic compounds may be named by prefixing aza (N), oxa (O) or thio (S) to the corresponding hydrocarbon name.

K3.2 Physical Properties of PAH

Based on data in Table K3-1, Figures K3-1 and K3-2 illustrate the relationship between boiling point and PAH molecular weight and between solubility in water (at approximately 25°C) and molecular weight, respectively. As PAH compounds become more complex and molecular weight increases, boiling point also increases, from 218°C for double-ringed naphthalene to greater than 500°C for most six-ring compounds. Solubility decreases exponentially with molecular weight. Most compounds comprised of four rings or more are essentially water-insoluble.

K4. TREATMENT OF NONDETECTABLES IN THE GROUND-WATER DATA BASE

Frequently, compound concentrations are reported to be below method detection limits. In evaluating analytical results, a concentration of 0 parts per trillion is generally associated with the undetected compounds. However, it is also important to relate a specific detection limit to each undetected compound. In order to address both of these needs, the data base maintains two records of each sample.

One set of records reports a concentration of 0.001 parts per trillion for each undetected compound. In the second set of records, analysis results found to be below detection limits are entered as the detection limit + 0.001. For example, if benzo(a)pyrene were undetected at a detection limit of 20 parts per trillion, the associated concentration would be entered in the first record as 0.001 and in the second as 20.001. The digit one in the third decimal place is used merely as a flag to distinguish between detected compounds, undetected compounds and compounds that are listed in the data base but were not included in the analysis.

K5. UTILIZATION OF THE GROUND-WATER DATA BASE

The data have been utilized in many ways to provide information on ground water quality. They have been used to compare the concentration of individual compounds, such as phenol or benzo(a)pyrene, between wells and to determine which compounds were found most frequently in specific groups of wells. The two principal applications of the data base have been in determining total PAH concentration in ground-water samples and, through the use of the PAH criteria defined in Chapter 4, assessing the level of contamination of selected wells.

K5.1 Total PAH Calculations

Data in the ground-water data base represent analyses performed by many different laboratories and by several different analytical methods. Gas chromatography/mass spectroscopy (GC/MS) was used by CH2M Hill, Capsule Laboratories and MRC. High performance liquid chromatography (HPLC) was used by MDH, Serco, and the EPA. Midwest

Research Institute (MRI) analyzed all samples by GC/MS; those samples in which no PAH and related compounds were detected were then analyzed by HPLC. As Table K5-1 illustrates, each laboratory analyzed for a different set of compounds. To enable comparisons of total PAH between samples from different laboratories, a set of twelve PAH common to Minnesota Department of Health, CH2M Hill and Capsule Laboratories* were selected to form the basis for total PAH calculations. These selected PAH are indicated in Table K5-1. Total PAH data have been used to analyze spatial and temporal trends in PAH concentration.

K5.2 Assessment of Well Contamination

The other major use of the ground-water data base has been to provide data to assess the level of contamination in various wells. Using the proposed PAH criteria established in Chapter 4 of this report, each compound has been identified as either carcinogenic or noncarcinogenic. The data base compounds are listed by carcinogen class in Table K5-2. Tables K5-3 through K5-6 are data base-generated reports of total carcinogens and noncarcinogens for St. Louis Park, Hopkins and Edina municipal wells and numerous private and/or monitoring wells in and around St. Louis Park. Totals include only the compounds listed in Table K3-1. Additional compounds noted in the comment field are not included. Table K5-7 is a comprehensive list of all phenolics data currently in the ground-water data base. In these tables, each sample is identified by well code, sample date and report ID. Dates are listed in YYMMDD format. Where sample dates were not reported in the original data source, the listed date represents the date the sample was received or analyzed. Well codes are cross referenced to more detailed information in Table K5-8, and the abbreviated report ID's are cross referenced to literature citations in Table K5-9.

*These three laboratories were selected because as a group they have provided the most extensive PAH data in the ground-water data base.

Figures 4-2 through 4-8 in Chapter 4 were generated from data in Tables K5-3 and K5-4 and include analyses by MDH, Capsule Laboratories, CH2M Hill, MRC and Serco. All December 1978 sample analyses in these figures represent undated 1978 MDH analyses.

K5.3 Molecular Weight Profiles

Data from the ground-water data base have also been coupled with information in the PAH compound data base in order to better evaluate analysis results. For example, Figures K5-1 through K5-10 present molecular weight profiles of the most recent sample analyses currently in the data base for all closed municipal wells, as well as Texatonka Shopping Center (W32), Park Theater (W70) and Flame Industries (W29). With the exception of St. Louis Park Wells SLP10 and SLP15 (where benz(a)anthracene and/or chrysene were detected), no carcinogenic PAH are reported for the closed wells; SLP15 alone exceeded the carcinogenic criterion. Acenaphthene, fluorene and acenaphthylene, which are all relatively low molecular-weight noncarcinogenic compounds, were detected most frequently and in highest concentration.

K6. REFERENCES*

Anderson, H. C. and W. R. K. Wu, 1963. "Properties of Compounds in Coal-Carbonization Products." Bureau of Mines Bulletin 606.

Lee, M. L., M.V. Novotny and K. D. Bartle, 1981. Analytical Chemistry of Polycylic Aromatic Compounds. Academic Press.

Pearlman, R. S., S. H. Yalkowski and S. Barjeree, 1983. "Water Solubilities of Polynuclear Aromatic and Heteroaromatic Compounds." Currently in press.

Pucknat, A. W. 1981. Health Impacts of Polynuclear Aromatic Hydrocarbons. Noyes Data Corp.

*These references are in addition to those cited in Table K5-9.

TABLE K2-1

COMPOUNDS INCLUDED IN THE

GROUND-WATER DATA BASE

Acenaphthylene

Acenaphthene

Anthracene

Benzo(a)anthracene

Benzo(a)pyrene

Benzo(b)fluoranthene

Benzo(c)phenanthrene

Benzo(e)pyrene

Benzo(ghi)perylene

Benzo(j)fluoranthene

Benzo(k)fluoranthene

Chrysene

Dibenzo(a,c)anthracene

Dibenzo(a,e)pyrene

Dibenzo(a,h)anthracene

Dibenzo(a,h)pyrene

Dibenzo(a,i)pyrene

7, 12 - dimethylbenz(a)anthracene

Fluorene

Fluoranthene

Indeno(1,2,3,-cd)pyrene

3-methylcholanthrene

Perylene

Phenanthrene

Pyrene

4, 5, 9, 10 - tetrahydropyrene

Triphenylene

Acridine

Benzo(b)thiophene

Benzofuran

TABLE K2-1 (cont't)

Carbazole
Indole
Methylbenzofuran
Phenanthradine
Quinoline
Biphenyl
2, 3-dihydroindene
Indene
1-methylnaphthalene
2-methylnaphthalene
Naphthalene

TABLE K3-1

PAH COMPOUND DATA BASE

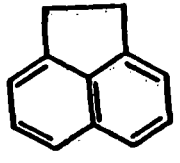
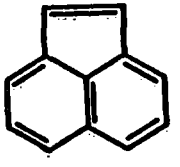
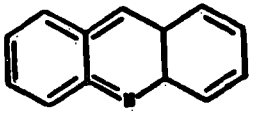
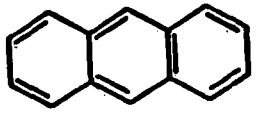
NAME	Reg. #	# Ring	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Acenaphthene 1,2-Dihydroacenaphthylene Peri-Ethylenenaphthylene 1:8-Dimethylane-naphthalene	83-32-9	3	$C_{12}H_{10}$	154	Sol Mg/l H_2O=3.93 M.P. = 95°C B.P. = 278°C	
Acenaphthylene	208-96-8	3	$C_{12}H_8$	152	Sol Mg/l H_2O= M.P. = 92°C B.P. = 265°C	
Acridine 2,3-Benzoquinoline	260-94-6	3	$C_{13}H_9N$	179	Sol Mg/l H_2O= .064 M.P. = 111°C B.P. = 346°C	
Anthracene	120-12-7	3	$C_{14}H_{10}$	178	Sol Mg/l H_2O= .073 M.P. = 217°C B.P. = 340°C	

TABLE K3-1 (Continued)

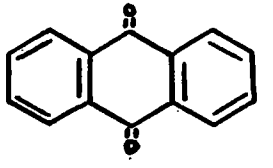
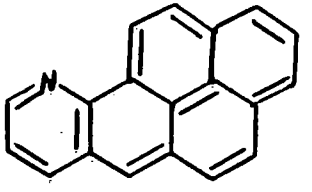
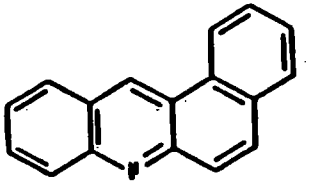
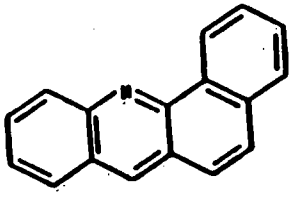
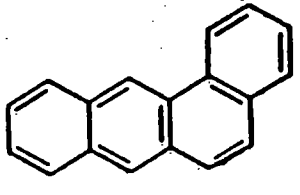
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Anthraquinone	84-65-1	3	$C_{14}H_8O_2$	208	Sol Mg/l H_2O= M. P. = 284°C B. P. = 380°C	
10-Azabenzo (a) pyrene Phenaleno-(1,9-gh)quinoline	189-92-4	5	$C_{19}H_{11}N$	253	Sol Mg/l H_2O= M. P. = B. P. =	
Benz (a) Acridine 1,2-Benzacridine	225-11-6	4	$C_{17}H_{11}N$	229	Sol Mg/l H_2O= M. P. = 132°C B. P. = 438°C	
Benz (c) Acridine 3,4-Benzacridine	225-51-4	4	$C_{17}H_{11}N$	229	Sol Mg/l H_2O= M. P. = 109°C B. P. = 434°C	
Benz (a) Anthracene tetraphene 1,2-Benzanthracene 2,3-Benzophenanthrene	56-55-3	4	$C_{18}H_{12}$	228	Sol Mg/l H_2O= M. P. = 159.5°C B. P. = 400°C	

TABLE K3-1 (Continued)

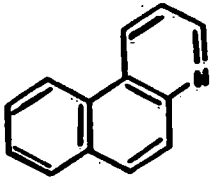
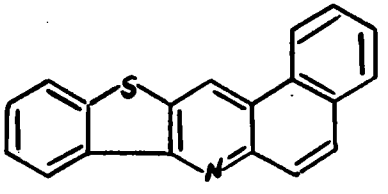
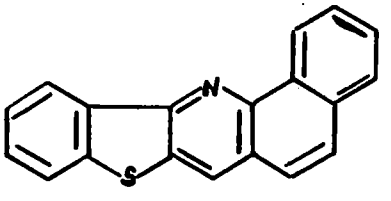
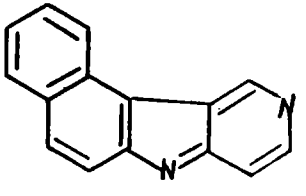
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Benz (F) isoquinoline **2-Azaphenanthrene**	229-67-4	3	$C_{13}H_9N$	179	Sol Mg/l H_2O= M. P. = B. P. =	
Benzo (f) benzo (2,3)– thieno (3,2-b) quinoline Benzo (f) (1) benzo thieno – (3,2-b) quinoline	1491-10-7	5	$C_{19}H_{12}NS$	286	Sol Mg/l H_2O= M. P. = B. P. =	
Benzo (h) benzo (2,3) thieno – (3,2-b) quinoline Benzo (h) (1) benzothieno – (3,2-b) quinoline	1491-09-4	5	$C_{19}H_{12}NS$	286	Sol Mg/l H_2O= M. P. = B. P. =	
7H Benzo (g) γ-Carboline	-				Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

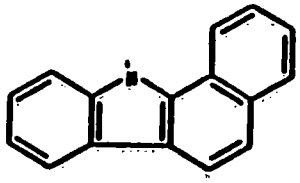
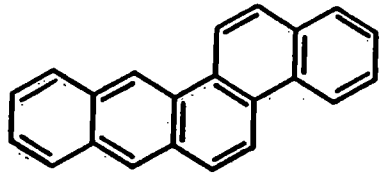
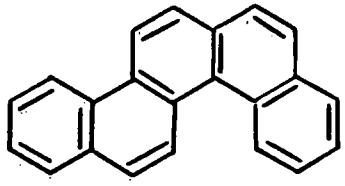
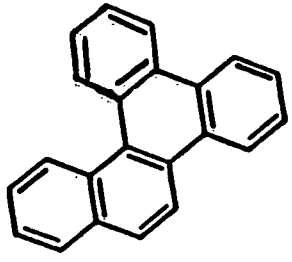
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Benzo (a) Carbazole 1,2-Benzocarbazole α-Benzocarbazole	239-01-0	4	$C_{16}H_{11}N$	217	Sol Mg/l H_2O= M. P. =235°C B. P. =450°C	
Benzo (b) Chrysene 3,4-Benzotetraphene	214-17-5	5	$C_{22}H_{14}$	278	Sol Mg/l H_2O= M. P. = B. P. =	
Benzo (c) Chrysene Dibenzo (a,g) phenanthrene	194-69-4	5	$C_{22}H_{14}$	278	Sol Mg/l H_2O= M. P. = B. P. =	
Benzo (g) Chrysene	196-78-1	5	$C_{22}H_{14}$	278	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

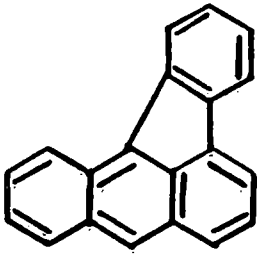
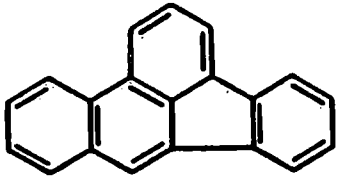
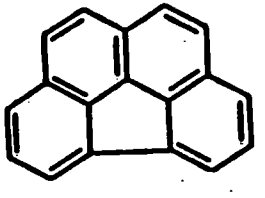
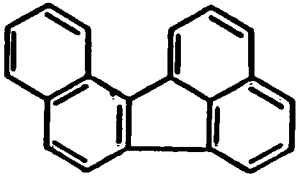
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Benzo (a) fluoranthene Benzo (a) aceanthrylene Dibenzo (c, lm) fluorene 1,2-benzofluoranthene	203-33-8	5	$C_{20}H_{12}$	252	Sol Mg/l H_2O= M. P. = B. P. =	
Benzo (b) fluoranthene Benzo (e) acephenanthrylene 2,3-benzofluoranthene	205-99-2	5	$C_{20}H_{12}$	252	Sol Mg/l H_2O= M. P. =167°C B. P. =481°C	
Benzo (ghi) fluoranthrene 7,10-Benzofluoranthene	203-12-3	5	$C_{18}H_{10}$	226	Sol Mg/l H_2O= M. P. =140°C B. P. =432°C	
Benzo (j) fluoranthene 7,8-Benzofluoranthene 10,11-Benzofluoranthene	205-82-3	5	$C_{20}H_{12}$	252	Sol Mg/l H_2O= M. P. = 165°C B. P. = 480°C	

TABLE K3-1 (Continued)

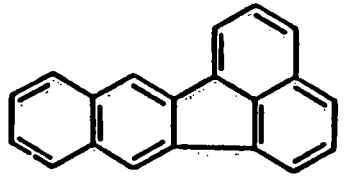
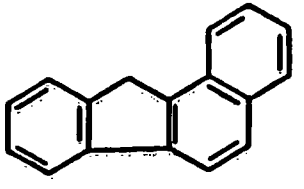
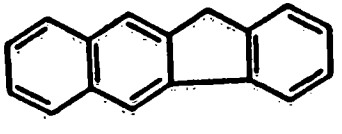
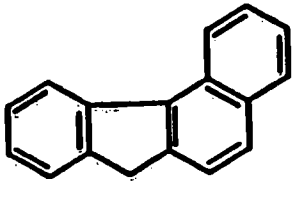
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Benzo (k) fluoranthene 8,9-Benzofluoranthene 11,12-Benzofluoranthene	207-08-9	5	$C_{20}H_{12}$	252	Sol Mg/l H_2O= 0.0008 M. P. =215°C B. P. =480°C	
11H-Benzo(a) fluorene 1,2-Benzofluorene Chrysofluorene	238-84-6	4	$C_{17}H_{12}$	216	Sol Mg/l H_2O= M. P. =188°C B. P. =407°C	
11H-Benzo (b) fluorene 2,3-Benzofluorene	243-17-4	4	$C_{17}H_{12}$	216	Sol Mg/l H_2O= M. P. =209.5°C B. P. =401°C	
7H-Benzo (c) fluorene 3,4-Benzofluorene	205-12-9	4	$C_{17}H_{12}$	216	Sol Mg/l H_2O= M. P. =125°C B. P. =406°C	

TABLE K3-1 (Continued)

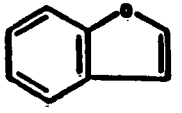
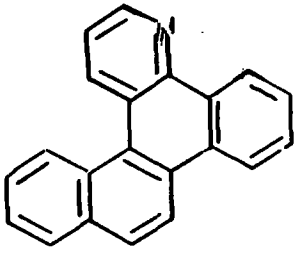
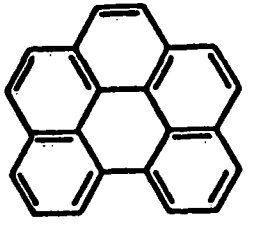
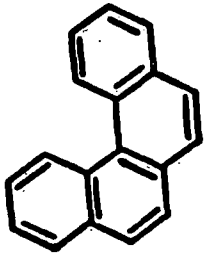
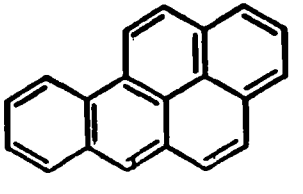
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Benzofuran Coumarone	271-89-6	2	C_8H_6O	118	Sol Mg/l H_2O= M. P. = B. P. =173°C	
Benzo (h) naphtho (1,2-f)-quinoline	196-79-2	5	$C_{21}H_{14}N$	280	Sol Mg/l H_2O= M. P. = B. P. =	
Benzo (ghi)Perylene 1,12-Benzoperylene	191-24-2	6	$C_{22}H_{12}$	276	Sol Mg/l H_2O= M. P. =273°C B. P. =+500°C	
Benzo (c) Phenanthrene 3,4-Benzo (c) phenanthrene	195-19-7	4	$C_{18}H_{12}$	228	Sol Mg/l H_2O= M. P. =68°C B. P. =	
Benzo (a) Pyrene 1,2-Benzopyrene 3,4-Benzopyrene	50-32-8	5	$C_{20}H_{12}$	252	Sol Mg/l H_2O=0.005 M. P. =178.8°C B. P. =495°C	

TABLE K3-1 (Continued)

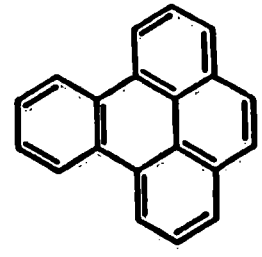
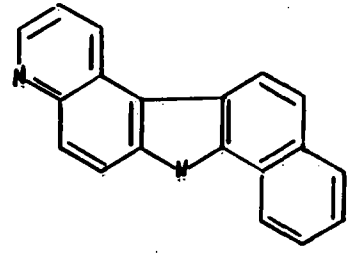
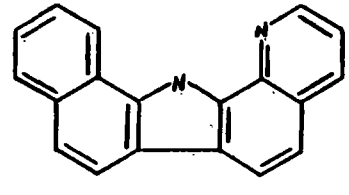
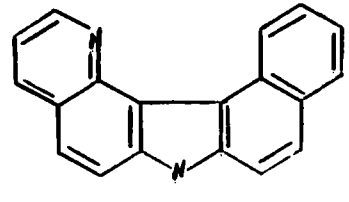
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Benzo (e) pyrene 4,5-Benzopyrene	192-97-2	5	$C_{20}H_{12}$	252	Sol Mg/l H_2O= .006 M. P. = 178.9°C B. P. = 493°C	
7H-Benzo (a) pyrido (3,2-g)-carbazole	207-89-6	5	$C_{19}H_{12}N_2$	268	Sol Mg/l H_2O= M. P. = B. P. =	
13H-Benzo (a) pyrido (3,2-i)-carbazole	239-67-8	5	$C_{19}H_{12}N_2$	268	Sol Mg/l H_2O= M. P. = B. P. =	
7H-Benzo (c) pyrido (2,3-g)-carbazole	-	5	$C_{19}H_{12}N_2$	268	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

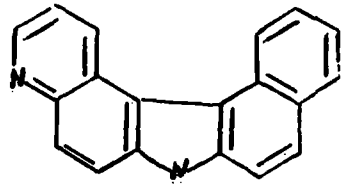
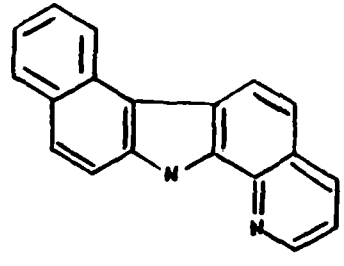
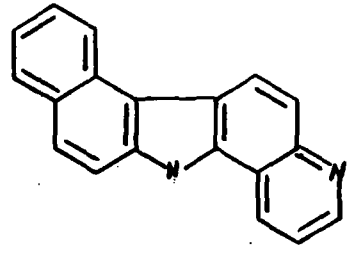
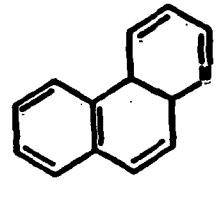
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
7H-Benzo (c) pyrido (3,2-g)-carbazole	-	5	$C_{19}H_{12}N_2$	268	Sol Mg/l H_2O= M. P. = B. P. =	
7H-Benzo (g) pyrido (2,3-a)-carbazole	-	5	$C_{19}H_{12}N_2$	268	Sol Mg/l H_2O= M. P. = B. P. =	
7H-Benzo (g) pyrido (3,2-a)-carbazole	-	5	$C_{19}H_{12}N_2$	268	Sol Mg/l H_2O= M. P. = B. P. =	
Benzo (f) quinoline 5,6-Benzoquinoline 1-Azophenanthrene	85-02-9	3	$C_{13}H_9N$	179	Sol Mg/l H_2O= M. P. =91.5°C B. P. =350°C	

TABLE K3-1 (Continued)

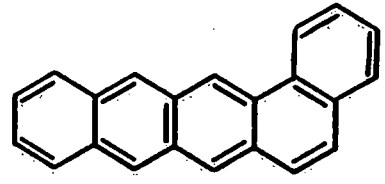
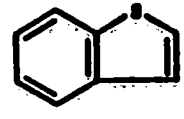
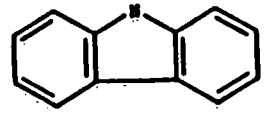
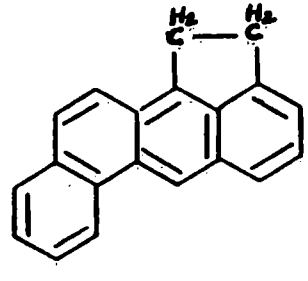
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Benzo (a) tetracene Benzo (a) Naphthacene	226-88-0	5	$C_{22}H_{14}$	278	Sol Mg/l H_2O= M. P. = B. P. =	
Benzo (b) thiophene 2,3-Benzothiophene thianaphthene thionaphthene	95-15-8	2	C_8H_6S	134	Sol Mg/l H_2O= M. P. = 29°C B. P. = 221°C	
Carbazole	86-74-8	3	$C_{12}H_9N$	167	Sol Mg/l H_2O= M. P. = 246°C B.P. = 355°C	
Cholanthrene 7,8-Dimethylenebenz (a) — anthracene 1,2-dihydrobenz (j) — aceanthrylene	479-23-2	5	$C_{20}H_{14}$	254	Sol Mg/l H_2O M. P. = B. P. =	

TABLE K3-1 (Continued)

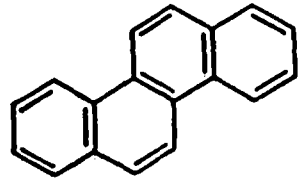
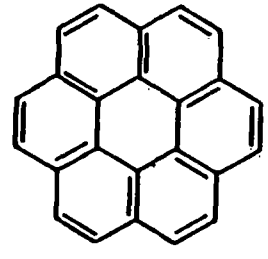
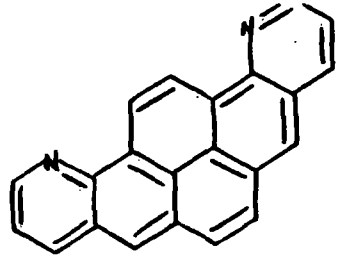
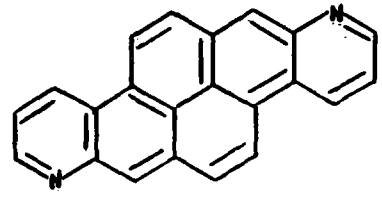
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Chrysene	218-01-9	4	$C_{18}H_{12}$	228	Sol Mg/l H_2O= .0018 M. P. = 251 C B. P. = 448 C	
Coronene Hexabenzobenzene	191-07-1	7	$C_{24}H_{12}$	300	Sol Mg/l H_2O= M. P. = 440 C B. P. = 525 C	
1,12-Diazabenzo (rst)-pentaphene	-	6	$C_{20}H_{12}N_2$	280	Sol Mg/l H_2O= M. P. = B. P. =	
4,11-Diazadibenzo (b,def)-chrysene	-	6	$C_{22}H_{12}N_2$	290	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

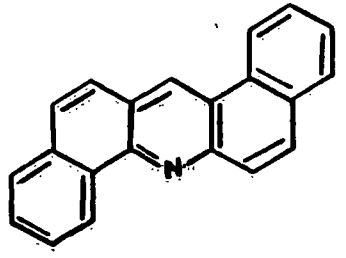
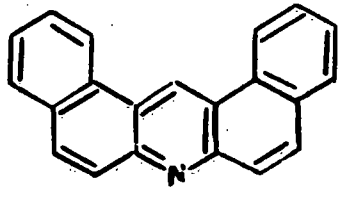
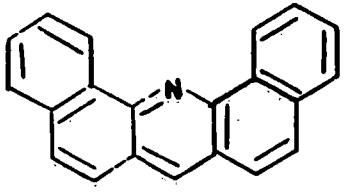
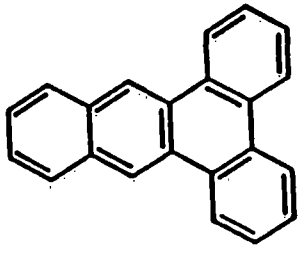
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Dibenz (a,h) acridine 7-Azadibenz (a,h) anthracene 1,2: 5,6-Debenzacridine Dibenz (a,d) acridine 1,2,5,6-Dibenzacridine 1,2,5,6-Dibenzoacridine Dibenz (ah) acridine	226-36-8	5	$C_{21}H_{13}N$	279	Sol Mg/l H_2O= M. P. = B. P. =	
Dibenz (a,j) Acridine 7-Azadibenz (a,j) anthracene 1,2: 7,8-Dibenzacridine Dibenzo (a,j) acridine Dibenz (a,f) acridine 1,2,7,8-Dibenzacridine	224-420	5	$C_{21}H_{13}N$	279	Sol Mg/l H_2O= M. P. = B. P. =	
Dibenz (c, h) Acridine 3,4: 5,6-Dibenzacridine 14-Azadibenz (a,j) anthracene	224-53-3	5	$C_{21}H_{13}N$	279	Sol Mg/l H_2O= M. P. = B. P. =	
Dibenz (a,c) anthracene 1,2:3,4-dibenzanthracene Benzo (b) triphenylene	215-58-7	5	$C_{22}H_{14}$	278	Sol Mg/l H_2O= M. P. = 205°C B. P. = 518°C	

TABLE K3-1 (Continued)

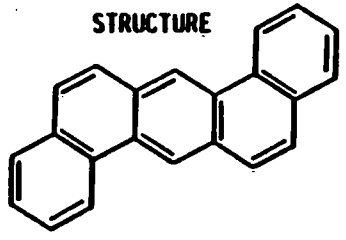
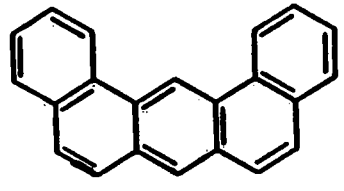
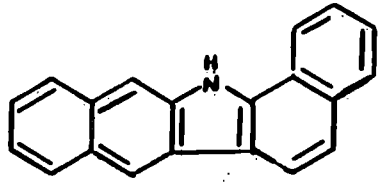
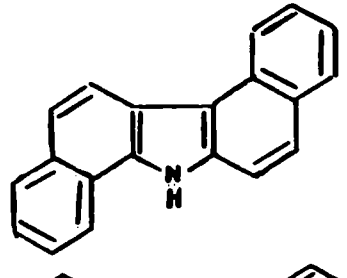
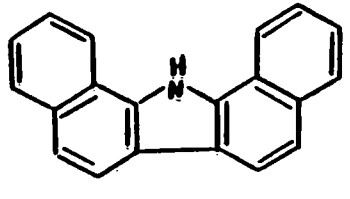
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Dibenz (a,h) Anthracene 1,2:5,6-Dibenzanthracene	53-70-3	5	$C_{22}H_{14}$	278	Sol Mg/l H_2O= .0005 M. P. = 266°C B. P. = 524°C	
Dibenz (a,j) anthracene 1,2:7,8-Dibenzanthracene pyranthrene	191-13-9	5	$C_{22}H_{14}$	278	Sol Mg/l H_2O= M. P. = 198°C B. P. =	
13H-Dibenzo (a,h) Carbazole 13-Aza-13H-dibenzo (a,h) fluorene 1,2:6,7-Dibenzocarbazole	239-88-3	5	$C_{20}H_{14}N$	267	Sol Mg/l H_2O= M. P. = B. P. =	
7H-Dibenzo (a,g) Carbazole 1,2:5,6-Dibenzocarbazole Dibenzo (a,g) carbazole 1,2,5,6-Dibenzocarbazole	207-84-1	5	$C_{20}H_{13}N$	267	Sol Mg/l H_2O= M. P. = B. P. =	
13H-Dibenzo (a,i) carbazole 13-Aza-13H-dibenzo (a,i) fluorene 1,2:7,8-Dibenzocarbazole	239-64-5	5	$C_{20}H_{13}N$	267	Sol Mg/l H_2O= M. P. =220.5°C B. P. =220.5°C	

TABLE K3-1 (Continued)

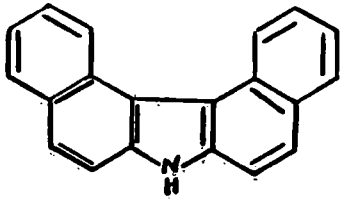
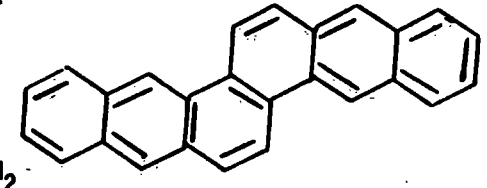
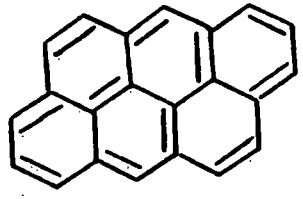
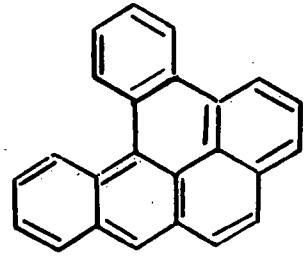
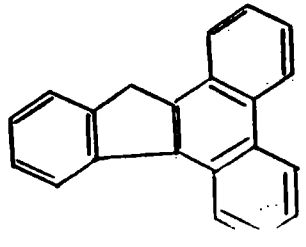
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
7H-Dibenzo (c,g)-Carbazole 7-Aza-7H-dibenzo-(c,g) fluorene 3,4,5,6-Dibenzo-carbazole	194-59-2	5	$C_{20}H_{13}N$	267	Sol Mg/l H_2O= M. P. = B. P. =	
Dibenzo (b,k) Chrysene	217-54-9	6	$C_{26}H_{16}$	378	Sol Mg/l H_2O= M. P. = B. P. =	
Dibenzo (def, mno)-Chrysene Dibenzo (cd, jk)-pyrene Anthanthrene Anthanthren	191-26-4	6	$C_{22}H_{12}$	276	Sol Mg/l H_2 M. P. = B. P. =	
Dibenzo (def,P) Chrysene **Dibenzo (a,l) pyrene**	191-30-0	6	$C_{24}H_{14}$	302	Sol Mg/l H_2O= M. P. = B. P. =	
13H-Dibenzo (a,c)-fluorene 13H-Indeno (1,2-1)-phenanthrene	201-65-0	5	$C_{21}H_{14}$	266	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

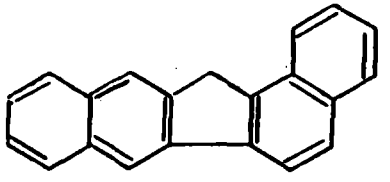
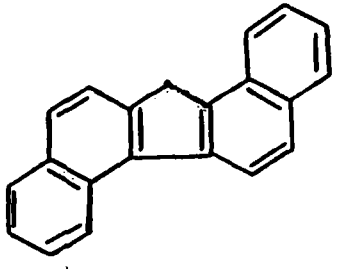
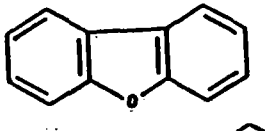
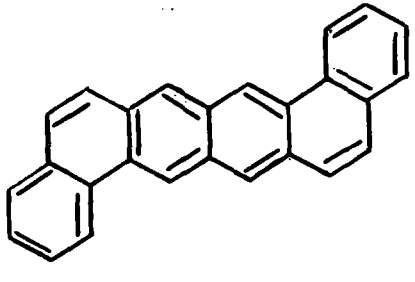
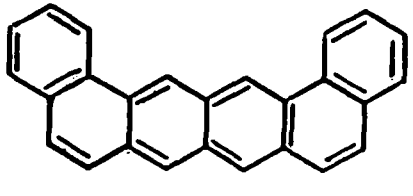
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
13H-Dibenzo (a,h) fluorene 1,2:6,7-Dibenzofluorene	239-85-0	5	$C_{21}H_{14}$	266	Sol Mg/l H_2O= M. P. = B. P. =	
13H-Dibenzo (a,g) fluorene 1,2,5,6-Dibenzofluorene Dibenzo (a,g) fluorene	207-83-0	5	$C_{21}H_{14}$	266	Sol Mg/l H_2O= M. P. = B. P. =	
Dibenzofuran 2,2'-Diphenylene oxide 2,2'-Biphenylene oxide	132-64-9	3	$C_{12}H_8O$	168	Sol Mg/l H_2O= M. P. = 85°C B. P. = 287°C	
Dibenzo (a,j) naphthacene	227-04-3	6	$C_{26}H_{16}$	328	Sol Mg/l H_2O= M. P. = B. P. =	
Dibenzo (a,l) naphthacene 1,2:9,10-Dibenzotetracene Dibenzo-1,2:9,10-naphthacene	226-86-8	6	$C_{26}H_{16}$	328	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

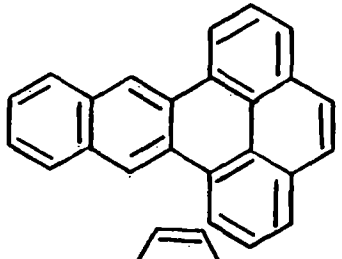
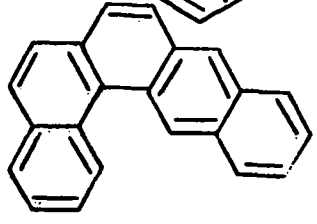
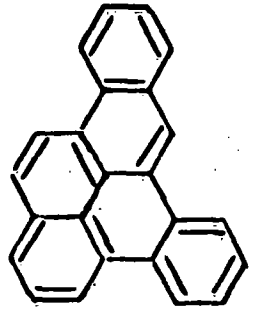
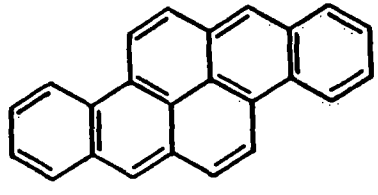
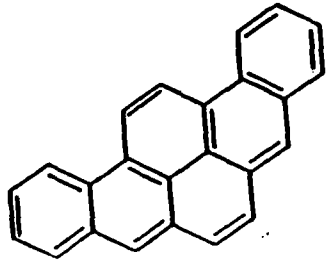
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Dibenzo (de, qr)-naphthacene	193-09-9	6	$C_{24}H_{14}$	302	Sol Mg/l H_2O= M. P. = B. P. =	
Dibenzo (b,g)-phenanthrene	195-06-2	5	$C_{22}H_{14}$	278	Sol Mg/l H_2O= M. P. = B. P. =	
Dibenzo (a,e)pyrene **Naphtho (1,2,3,4-eF)Chrysene** **1,2:4,5-Dibenzopyrene**	192-65-4	6	$C_{24}H_{14}$	302	Sol Mg/l H_2O= M. P. = 225°C B. P. =	
Dibenzo (a,h)pyrene **1,2:6,7-Dibenzopyrene** **3,4:8,9-Dibenzopyrene** **Dibenzo (b,def)chrysene**	189-64-0	6	$C_{24}H_{14}$	302	Sol Mg/l H_2O= M. P. =315°C B. P. =	
Dibenzo (a,i)pyrene **Benzo (rst)pentaphene** **1,2:7,8-Dibenzopyrene** **3,4:9,10-Dibenzopyrene**	189-55-9	6	$C_{24}H_{14}$	302	Sol Mg/l H_2O= M. P. = 282°C B. P. =	

TABLE K3-1 (Continued)

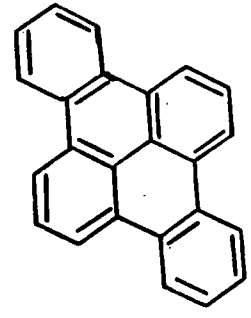
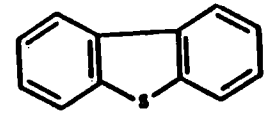
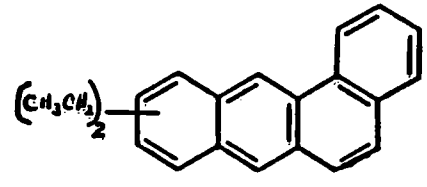
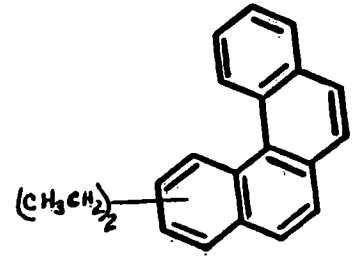
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Dibenzo (e, 1) pyrene Dibenzo (fg, op)— naphthacene	192-51-8	6	$C_{23}H_{14}$	290	Sol Mg/l H_2O= M. P. = B. P. =	
Dibenzothiophene Biphenylenesulfide	132-65-0	3	$C_{12}H_8S$	184	Sol Mg/l H_2O= M. P. = 98°C B. P. = 332°C	
Diethylbenz (a)— anthracene	-	4	$C_{22}H_{20}$	284	Sol Mg/l H_2O= M. P. = B. P. =	
Diethyl benzo (c) — phenanthrene	-	4	$C_{22}H_{20}$	284	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

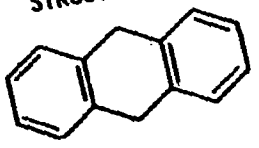
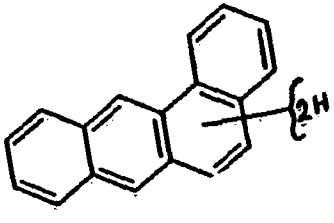
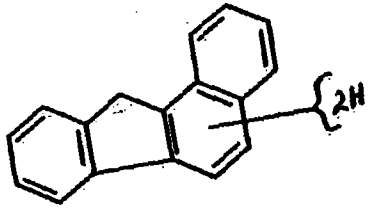
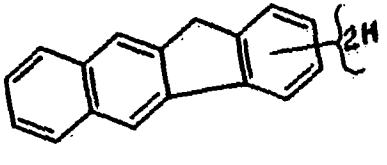
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
9,10-Dihydroanthracene	613-31-0	3	$C_{14}H_{12}$	180	Sol Mg/l H_2O= M. P. =110°C B. P. =312°C	
Dihydrobenz (a) anthracene	-	4	$C_{18}H_{14}$	230	Sol Mg/l H_2O= M. P. = B. P. =	
Dihydrobenzo (a) fluorene	41593-25-3	4	$C_{17}H_{14}$	218	Sol Mg/l H_2O= M. P. = B. P. =	
Dihydrobenzo (b) fluorene	41593-26-4	4	$C_{17}H_{14}$	218	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

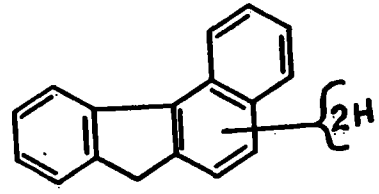
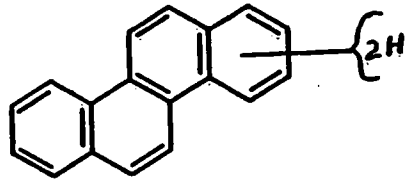
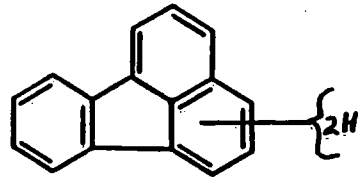
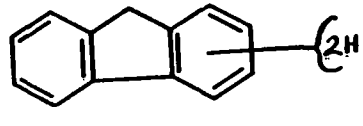
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Dihydrobenzo (c) fluorene	41593-27-5	4	$C_{17}H_{14}$	218	Sol Mg/l H_2O= M. P. = B. P. =	
Dihydrochrysene	41593-31-1	4	$C_{18}H_{14}$	230	Sol Mg/l H_2O= M. P. = B. P. =	
Dihydrofluoranthene	41593-24-2	4	$C_{16}H_{12}$	204	Sol Mg/l H_2O= M. P. = B. P. =	
Dihydrofluorene	41593-21-9	3	$C_{13}H_{12}$	168	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

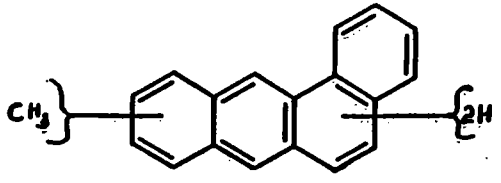
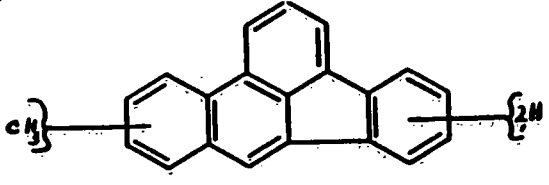
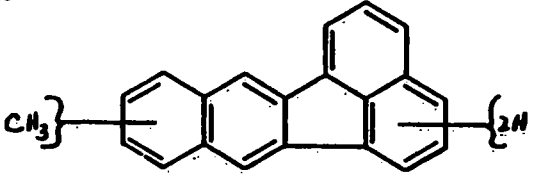
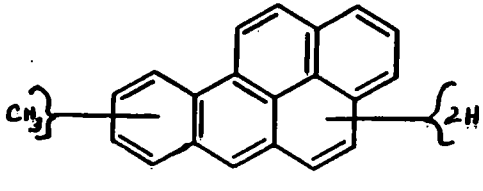
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Dihydromethylbenz (a) anthracene	-	4	$C_{19}H_{16}$	244	Sol Mg/l H_2O= M. P. = B. P. =	
Dihydromethylbenzo (b) fluoranthene	-	5	$C_{21}H_{14}$	268	Sol Mg/l H_2O= M. P. = B. P. =	
Dihydromethylbenzo (k) fluoranthene	39380-06-8	5	$C_{21}H_{14}$	268	Sol Mg/l H_2O= M. P. = B. P. =	
Dihydromethylbenzo (a) pyrene	3904-6	5	$C_{21}H_{14}$	268	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

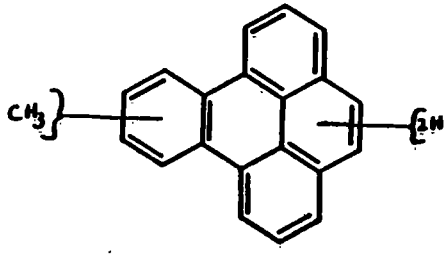
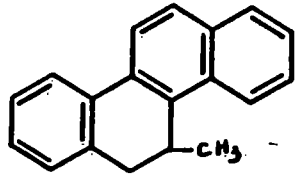
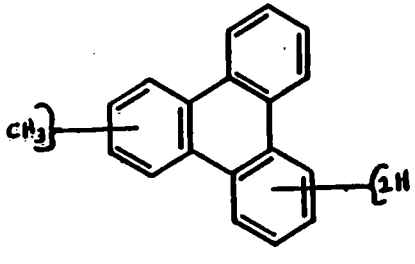
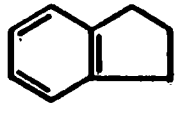
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Dihydromethylbenzo (e) pyrene	39380-05-7	5	$C_{21}H_{14}$	268	Sol Mg/l H_2O= M. P. = B. P. =	
5,6-Dihydro-5-methylchrysene	39379-95-8	4	$C_{19}H_{16}$	244	Sol Mg/l H_2O= M. P. = B. P. =	
Dihydromethyltriphenylene	-	4	$C_{19}H_{16}$	244	Sol Mg/l H_2O= M. P. = B. P. =	
2,3-Dihydroindene	496-11-7	2	C_9H_{10}	118	Sol Mg/l H_2O= M. P. =-51°C B. P. =177°C	

TABLE K3-1 (Continued)

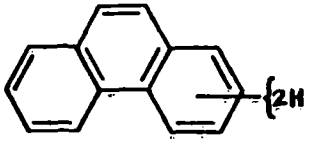
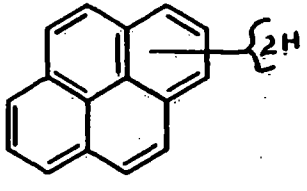
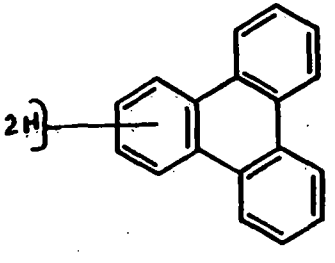
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
9,10-Dihydrophenanthrene	776-35-2	3	$C_{14}H_{12}$	180	Sol Mg/l H_2O= M. P. =35°C B. P. =168.5°C	
Dihydropyrene	28779-32-0	4	$C_{16}H_{12}$	204	Sol Mg/l H_2O= M. P. = B. P. =	
Dihydrotriphenylene	31423-95-7	4	$C_{18}H_{14}$	230	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

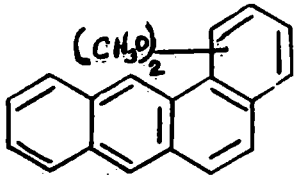
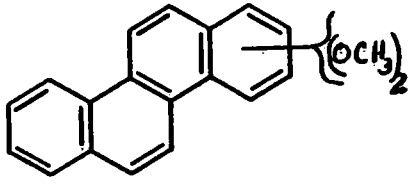
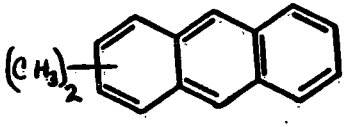
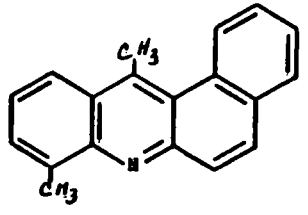
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Dimethoxybenz (a) anthracene	-	4	$C_{20}H_{16}O_2$	288	Sol Mg/l H_2O= M. P. = B. P. =	
Dimethoxychrysene	-	4	$C_{20}H_{16}O_2$	288	Sol Mg/l H_2O= M. P. = B. P. =	
Dimethyl anthracene	-	3	$C_{16}H_{14}$	206	Sol Mg/l H_2O= M. P. = B. P. =	
8,12-Dimethylbenz (a) Acridine	3518-05-6	4	$C_{19}H_{15}N$	257	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

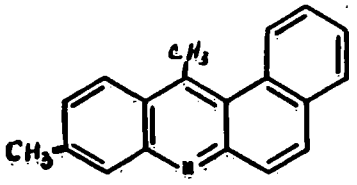
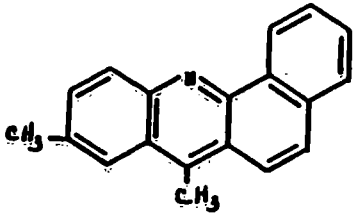
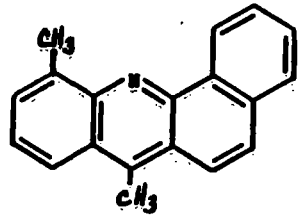
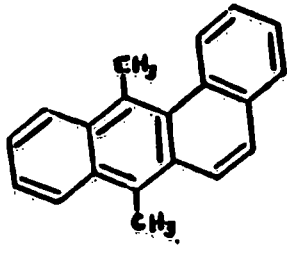
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
9,12-Dimethylbenz (a)—acridine	17401-48-8	4	$C_{19}H_{15}N$	257	Sol Mg/l H_2O= M. P. = B. P. =	
7,9-Dimethylbenz (c)—acridine	963-89-3	4	$C_{19}H_{15}N$	257	Sol Mg/l H_2O= M. P. = B. P. =	
7,11-Dimethylbenz (c)—acridine	32740-01-5	4	$C_{19}H_{15}N$	257	Sol Mg/l H_2O= M. P. = B. P. =	
7,12-Dimethylbenz (a)—anthracene	57-97-6	4	$C_{20}H_{16}$	256	Sol Mg/l H_2O= M. P. =122.5°C B. P. =	

TABLE K3-1 (Continued)

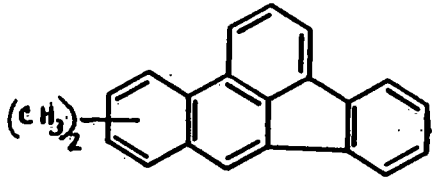
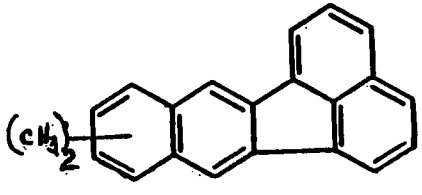
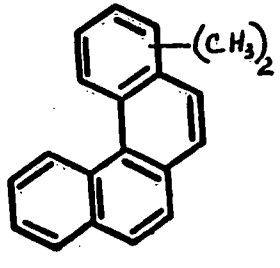
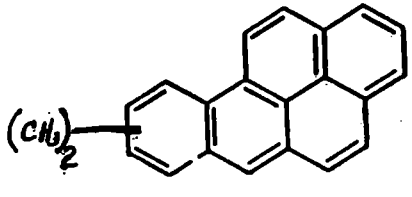
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Dimethylbenzo (b)-fluoranthene	-	5	$C_{22}H_{16}$	280	Sol Mg/l H_2O= M. P. = B. P. =	
Dimethylbenzo (K)-fluoranthene	-	5	$C_{22}H_{16}$	280	Sol Mg/l H_2O= M. P. = B. P. =	
Dimethylbenzo (c)-phenanthrene	-	4	$C_{20}H_{16}$	256	Sol Mg/l H_2O= M. P. = B. P. =	
Dimethylbenzo (a)-pyrene	-	5	$C_{22}H_{16}$	280	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

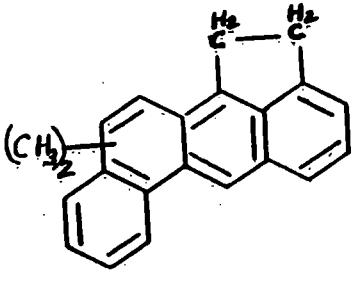
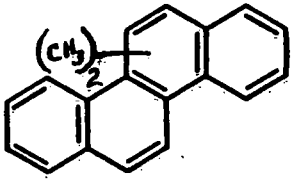
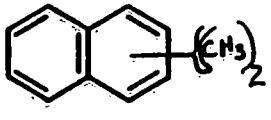
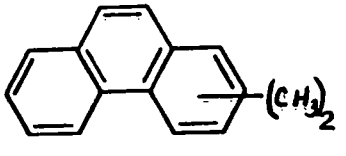
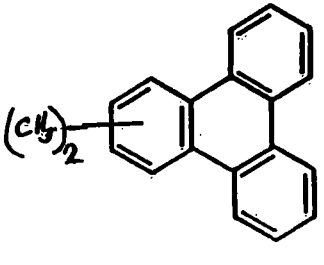
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Dimethyl Cholanthrene	-	5	$C_{22}H_{18}$	282	Sol Mg/l H_2O= M. P. = B. P. =	
Dimethylchrysene	-	4	$C_{20}H_{16}$	256	Sol Mg/l H_2O= M. P. = B. P. =	
Dimethylnaphthalene	-	2	$C_{12}H_{12}$	156	Sol Mg/l H_2O= M. P. = B. P. =	
Dimethyl phenanthrene	-	3	$C_{16}H_{14}$	206	Sol Mg/l H_2O= M. P. = B. P. =	
Dimethyltriphenylene	-	4	$C_{20}H_{16}$	256	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

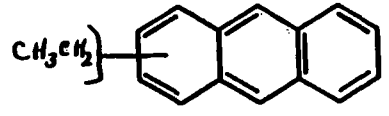
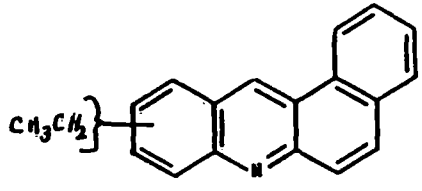
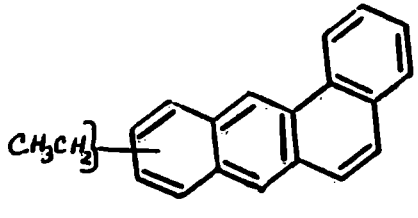
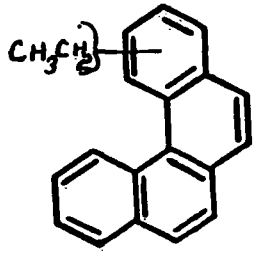
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Ethylanthracene	-	3	$C_{16}H_{14}$	206	Sol Mg/l H_2O= M. P. = B. P. =	
Ethylbenz (a)-acridine	-	4	$C_{19}H_{15}N$	257	Sol Mg/l H_2O= M. P. = B. P. =	
Ethyl benz (a)-anthracene	-	4	$C_{20}H_{16}$	256	Sol Mg/l H_2O= M. P. = B. P. =	
Ethylbenzo (c)-phenanthrene	-	4	$C_{20}H_{16}$	256	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

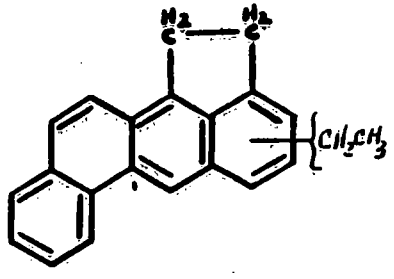
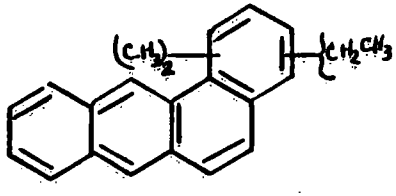
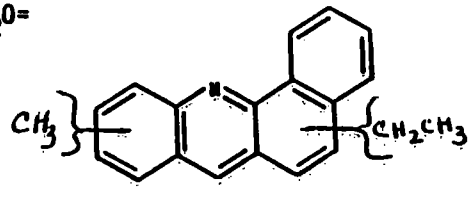
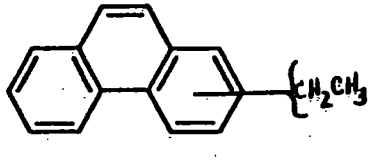
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Ethyl Cholanthrene	-	5	$C_{22}H_{18}$	282	Sol Mg/l H_2O= M. P. = B. P. =	
Ethyldimethylbenz (a)-anthracene	-	4	$C_{22}H_{20}$	284	Sol Mg/l H_2O= M. P. = B. P. =	
Ethylmethylbenz (c)-acridine	-	4	$C_{20}H_{17}N$	273	Sol Mg/l H_2O= M. P. = B. P. =	
Ethylphenanthrene	-	3	$C_{16}H_{14}$	206	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

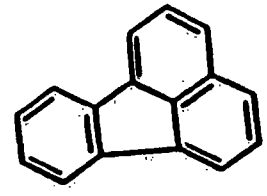
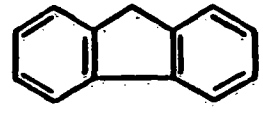
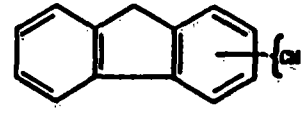
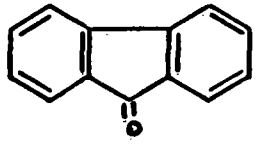
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Fluoranthene	206-44-0	4	$C_{16}H_{10}$	202	Sol Mg/l H_2O= M. P. =110°C B. P. =393°C	
Fluorene	86-73-7	3	$C_{13}H_{10}$	166	Sol Mg/l H_2O= M. P. =115°C B. P. =294°C	
Fluorenecarbonitrile	-	3	$C_{14}H_9N$	191	Sol Mg/l H_2O= M. P. = B. P. =	
Fluorenone	486-25-9	3	$C_{13}H_8O$	180	Sol Mg/l H_2O= M. P. =85°C B. P. =342°C	

TABLE K3-1 (Continued)

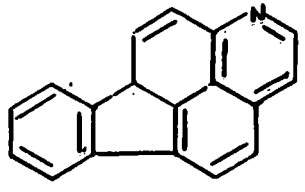
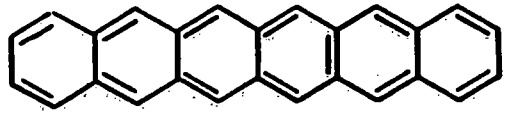
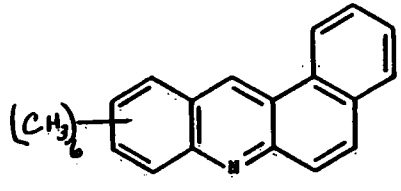
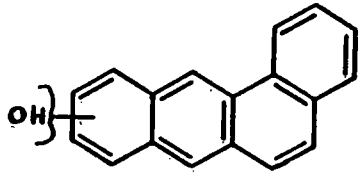
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Fluoreno (9,9a,1-gh)-quinoline	-	5	$C_{18}H_{10}N$	240	Sol Mg/l H_2O= M. P. = B. P. =	
Hexacene	258-31-1	6	$C_{26}H_{16}$	328	Sol Mg/l H_2O= M. P. = B. P. =	
Hexamethylbenz (a)-acridine	-	4	$C_{23}H_{23}N$	315	Sol Mg/l H_2O= M. P. = B. P. =	
Hydroxybenz (a)-anthracene	-	4	$C_{18}H_{12}O$	244	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

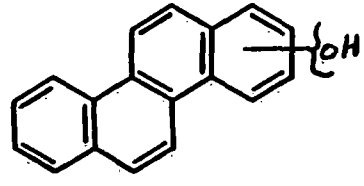
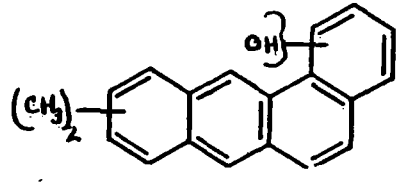
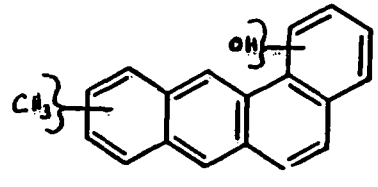
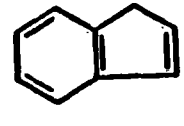
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Hydroxy Chrysene	-	4	$C_{18}H_{12}O$	244	Sol Mg/l H_2O= M. P. = B. P. =	
Hydroxydimethylbenz (a)—anthracene	-	4	$C_{20}H_{16}O$	272	Sol Mg/l H_2O= M. P. = B. P. =	
Hydroxymethylbenz (a)—anthracene	-	4	$C_{19}H_{14}O$	258	Sol Mg/l H_2O= M. P. = B. P. =	
Indene	95-13-6	2	C_9H_8	116	Sol Mg/l H_2O= M. P. =-3°C B. P. =181°C	

TABLE K3-1 (Continued)

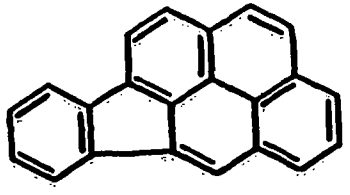
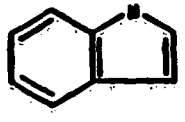
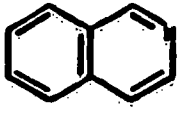
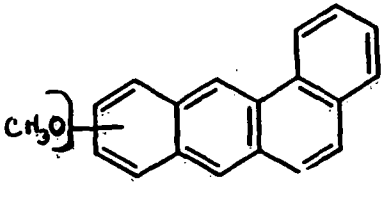
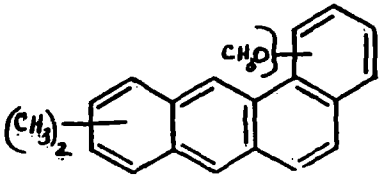
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Indeno (1,2,3-CD)pyrene O-phenylenepyrene	193-39-5	6	$C_{22}H_{12}$	276	Sol Mg/l H_2O=.0002 M. P. =162.5°C B. P. =	
Indole 1H-Indole 1-Benzazole 2,3-Benzopyrrole Ketole	120-72-9	2	C_8H_7N	117	Sol Mg/l H_2O=1872 M. P. =52°C B. P. =253°C	
Isoquinoline 2-Benzazine Leucoline	119-65-3	2	C_9H_7N	129	Sol Mg/l H_2O= 4515 M. P. =26°C B. P. =242°C	
Methoxybenz (a) anthracene	-	4	$C_{19}H_{14}O$	258	Sol Mg/l H_2O= M. P. = B. P. =	
Methoxydimethylbenz (a) anthracene	-	4	$C_{21}H_{18}O$	286	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

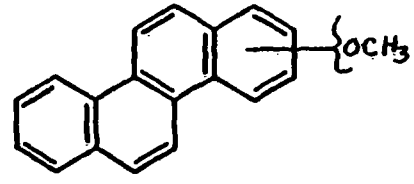
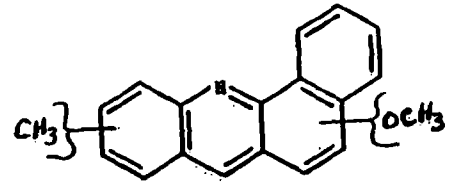
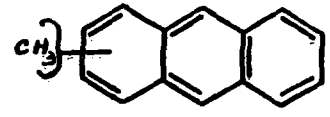
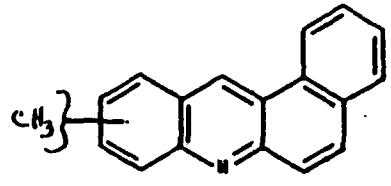
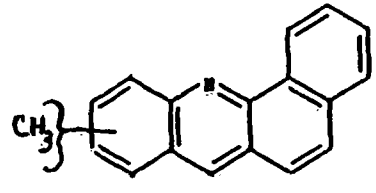
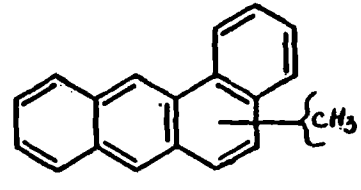
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Methoxy Chrysene	-	4	$C_{19}H_{14}O$	258	Sol Mg/l H_2O= M. P. = B. P. =	
Methoxymethylbenz (c)-acridine	-	4	$C_{19}H_{15}NO$	273	Sol Mg/l H_2O= M. P. = B. P. =	
Methylanthracene	-	3	$C_{15}H_{12}$	192	Sol Mg/l H_2O= M. P. = B. P. =	
Methylbenz (a)-acridine	-	4	$C_{18}H_{13}N$	243	Sol Mg/l H_2O= M. P. = B. P. =	
Methylbenz (c) acridine	-	4	$C_{18}H_{13}N$	243	Sol Mg/l H_2O= M. P. = B. P. =	
Methylbenz (a)-anthracene	-	4	$C_{19}H_{14}$	242	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

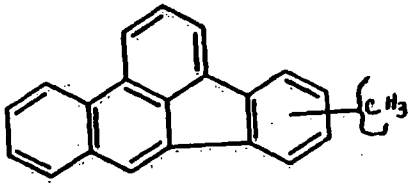
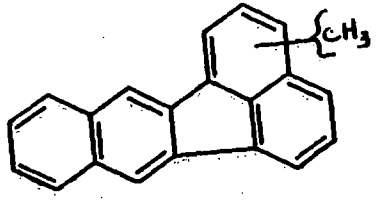
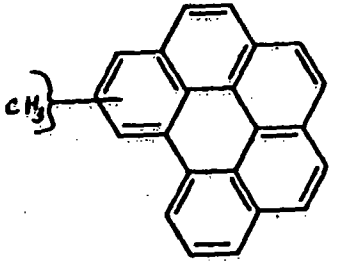
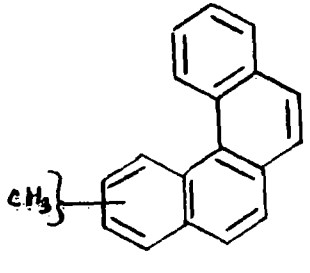
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Methylbenzo (b) fluoranthene	-	5	$C_{21}H_{12}$	266	Sol Mg/l H_2O= M. P. = B. P. =	
Methylbenzo (k) fluoranthene	-	5	$C_{21}H_{12}$	266	Sol Mg/l H_2O= M. P. = B. P. =	
Methylbenzo (ghi) perylene	-	6	$C_{23}H_{14}$	290	Sol Mg/l H_2O= M. P. = B. P. =	
Methylbenzo (c) phenanthrene	-	4	$C_{19}H_{14}$	242	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

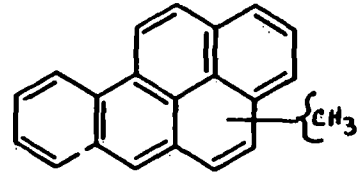
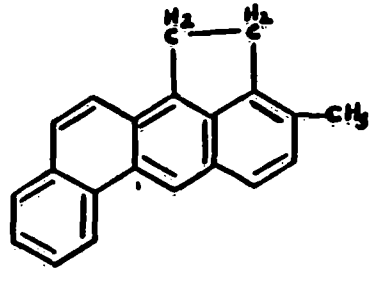
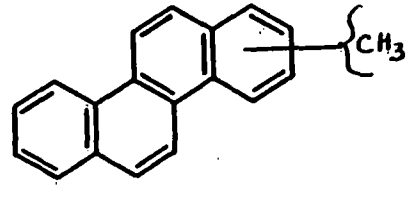
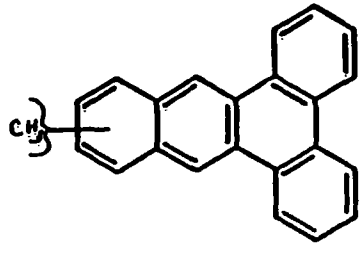
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Methylbenzo (a) pyrene	-	5	$C_{21}H_{14}$	268	Sol Mg/l H_2O= M. P. = B. P. =	
3-Methylcholanthrene 1,2-dihydro-3-Methylbenz(j)-aceanthrylene	56-49-5	5	$C_{21}H_{16}$	268	Sol Mg/l H_2O= M. P. =177°C B. P. =	
Methyl Chrysene	-	4	$C_{19}H_{14}$	242	Sol Mg/l H_2O= M. P. = B. P. =	
Methyldibenzanthracene	-	5	$C_{23}H_{16}$	292	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

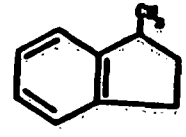
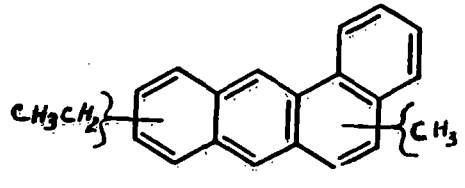
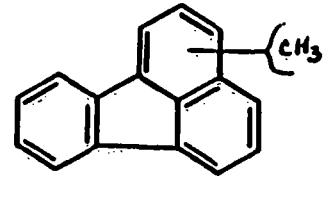
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
1-Methyl-2,3-dihydroindene	767-58-8	2	$C_{10}H_{12}$	132	Sol Mg/l H_2O= M. P. = B. P. =186°C	
Methylethylbenz (a)anthracene	-	4	$C_{21}H_{18}$	270	Sol Mg/l H_2O= M. P. = B. P. =	
Methylfluoranthene	-	4	$C_{17}H_{12}$	216	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

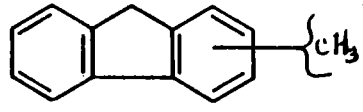
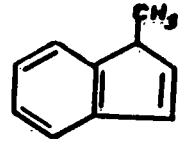
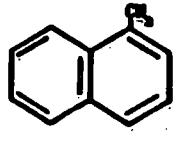
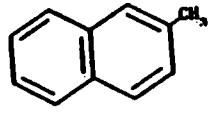
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Methylfluorene	-	3	$C_{14}H_{12}$	180	Sol Mg/l H_2O= M. P. = B. P. =	
1-Methyl-1H-Indene 1-Methylindene	767-59-9	2	$C_{10}H_{10}$	130	Sol Mg/l H_2O= M. P. = B. P. =	
1-Methylnaphthalene α-Methylnaphthalene	90-12-0	2	$C_{11}H_{10}$	142	Sol Mg/l H_2O=28.5 M. P. =-22°C B. P. =240°C	
2-Methylnapthalene β-Methylnaphthalene	91-57-6	2	$C_{11}H_{10}$	142	Sol Mg/l H_2O=25.4 M. P. =35°C B. P. =241°C	

TABLE K3-1 (Continued)

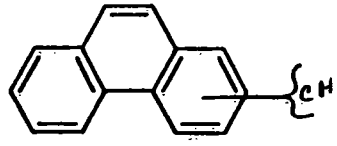
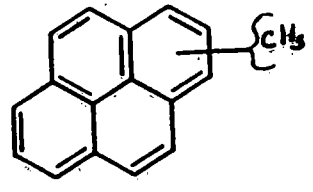
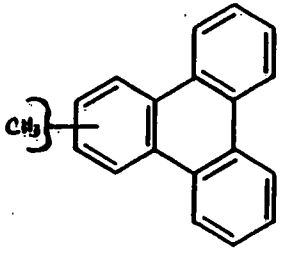
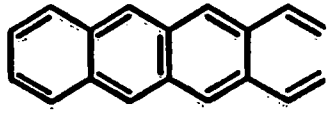
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Methylphenanthrene	-	3	$C_{15}H_{12}$	192	Sol Mg/l H_2O= M. P. = B. P. =	
Methylpyrene	-	4	$C_{17}H_{12}$	216	Sol Mg/l H_2O= M. P. = B. P. =	
Methyltriphenylene	-	4	$C_{19}H_{14}$	242	Sol Mg/l H_2O= M. P. = B. P. =	
Naphthacene Tetracene 2,3-benzanthracene	92-24-0	4	$C_{18}H_{12}$	228	Sol Mg/l H_2O= M. P. = ~343°C B. P. = ~450°C	

TABLE K3-1 (Continued)

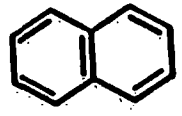
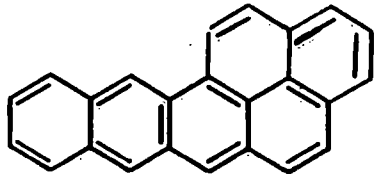
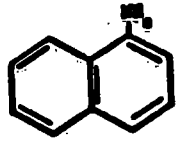
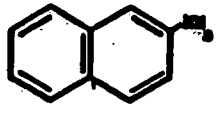
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Naphthalene	91-20-3	2	$C_{10}H_8$	128	Sol Mg/l H_2O=31.7 M. P. =80.2°C B. P. =217.9°C	
Naphtho (2,3-b) pyrene Naphtho (2,1,8-qrd) naphthacene	196-42-9	6	$C_{24}H_{14}$	302	Sol Mg/l H_2O= M. P. = B. P. =	
1-Naphthylamine α-Naphthaleneamine 1-Aminonaphthalene	134-32-7	2	$C_{10}H_9N$	143	Sol Mg/l H_2O= M. P. =50°C B. P. =301°C	
2-Naphthylamine β-Naphthaleneamine 2-Aminonaphthalene	91-59-8	2	$C_{10}H_9N$	143	Sol Mg/l H_2O= M. P. =113°C B. P. =294°C	

TABLE K3-1 (Continued)

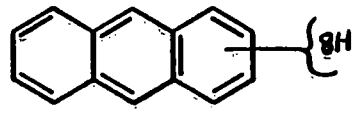
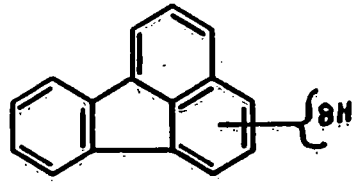
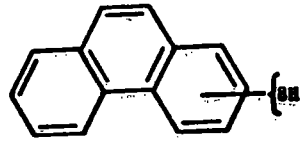
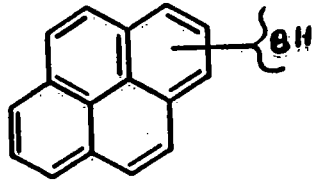
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Octahydroanthracene	26655-71-0	3	$C_{14}H_{18}$	186	Sol Mg/l H_2O= M. P. = B. P. =	
Octahydrofluoranthene	41593-22-0	4	$C_{16}H_{18}$	210	Sol Mg/l H_2O= M. P. = B. P. =	
Octahydrophenanthrene	-	3	$C_{14}H_{18}$	186	Sol Mg/l H_2O= M. P. = B. P. =	
Octahydropyrene	41593-23-1	4	$C_{16}H_{18}$	210	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

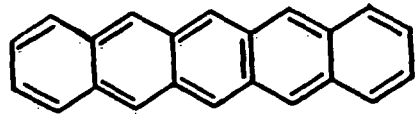
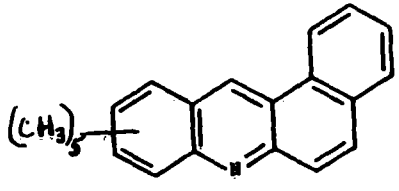
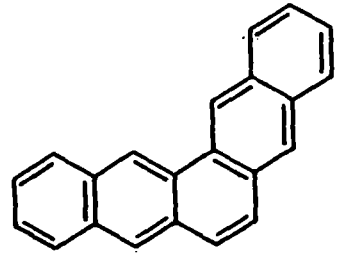
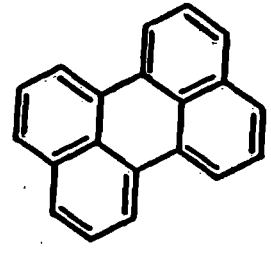
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Pentacene	135-48-8	5	$C_{22}H_{14}$	278	Sol Mg/l H_2O= M. P. = B. P. =	
Pentamethylbenz (a) acridine	-	4	$C_{22}H_{21}N$	299	Sol Mg/l H_2O= M. P. = B. P. =	
Pentaphene	222-93-5	5	$C_{22}H_{14}$	278	Sol Mg/l H_2O= M. P. = B. P. =	
Perylene	198-55-0	5	$C_{20}H_{12}$	252	Sol Mg/l H_2O=0.0004 M. P. =273°C B. P. =+500°C	

TABLE K3-1 (Continued)

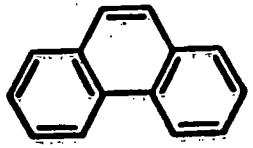
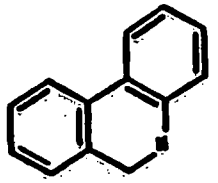
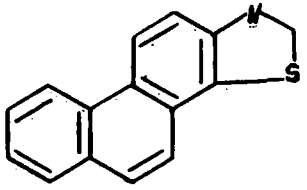
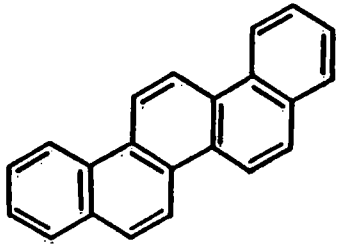
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Phenanthrene	85-01-8	3	$C_{14}H_{10}$	178	Sol Mg/l H_2O=1.29 M. P. =101°C B. P. =340°C	
Phenanthridine	229-87-8	3	$C_{13}H_9N$	179	Sol Mg/l H_2O= M. P. =105°C B. P. =349°C	
Phenanthro (2,1-d)-thiazole	14635-33-77	4	$C_{15}H_9NS$	235	Sol Mg/l H_2O= M. P. = B. P. =	
Picene 1,2:7,8 Dibenzophenanthrene Dibenzo (a,i) phenanthrene Benzo (a) Chrysene	213-46-7	5	$C_{22}H_{14}$	278	Sol Mg/l H_2O= M. P. =366°C B. P. =520°C	

TABLE K3-1 (Continued)

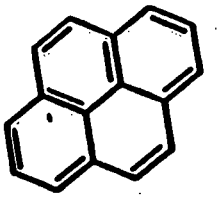
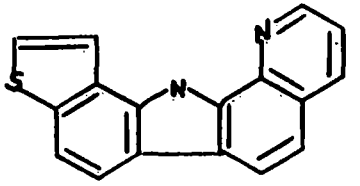
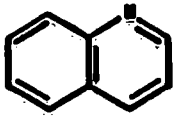
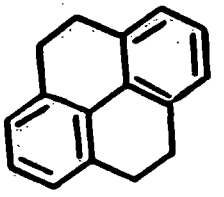
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Pyrene	129-00-0	4	$C_{16}H_{10}$	202	Sol Mg/l H_2O=0.135 M. P. =149°C B. P. =404°C	
12H pyridio (2,3-a) thieno-(2,3-i) carbazole	240-39-1	5	$C_{17}H_{10}N_2S$	274	Sol Mg/l H_2O= M. P. = B. P. =	
Quinoline	91-22-5	2	C_9H_7N	129	Sol Mg/l H_2O= M. P. =-15°C B. P. =237°C	
4,5,9,10-tetrahydropyrene	781-17-9	4	$C_{16}H_{14}$	206	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

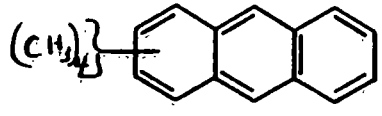
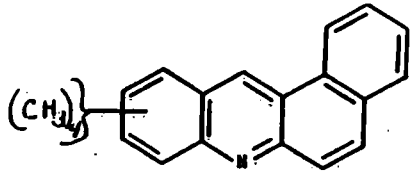
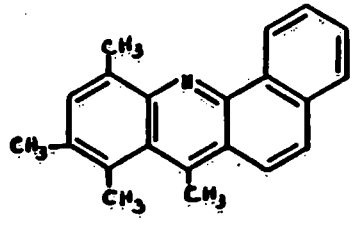
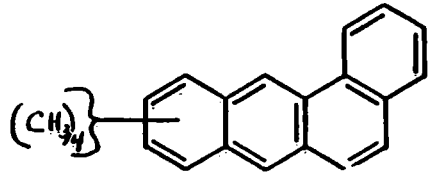
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Tetramethylanthracene	-	3	$C_{18}H_{18}$	234	Sol Mg/l H_2O= M. P. = B. P. =	
Tetramethylbenz (a)-acridine	-	4	$C_{21}H_{19}N$	285	Sol Mg/l H_2O= M. P. = B. P. =	
7,8,9,11-tetramethylbenz (c)-acridine	-	4	$C_{21}H_{19}N$	285	Sol Mg/l H_2O= M. P. = B. P. =	
Tetramethylbenz (a)-anthracene	-	4	$C_{22}H_{20}$	284	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

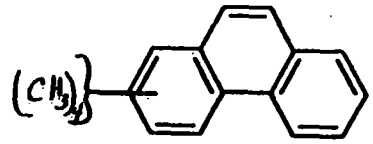
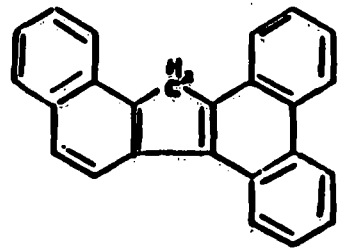
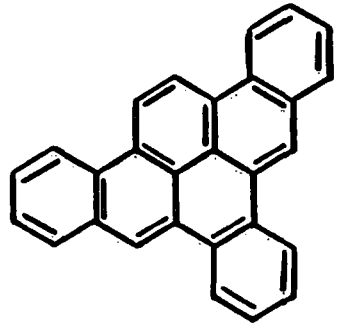
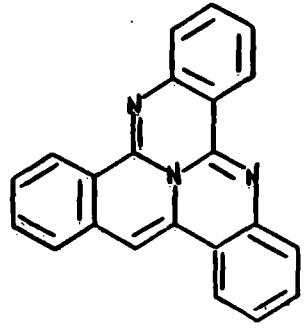
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Tetramethylphenanthrene	-	3	$C_{18}H_{18}$	234	Sol Mg/l H_2O= M. P. = B. P. =	
5H-tribenzo (a,c,i)fluorene	201-50-3	6	$C_{25}H_{16}$	316	Sol Mg/l H_2O= M. P. = B. P. =	
Tribenzo (a,e,i) pyrene		7	$C_{28}H_{16}$	352	Sol Mg/l H_2O= M. P. = B. P. =	
Tricycloquinoline	195-84-6	5	$C_{19}H_{12}N_2$	268	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

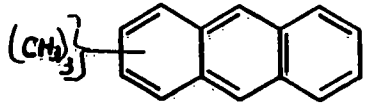
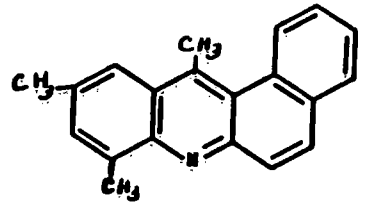
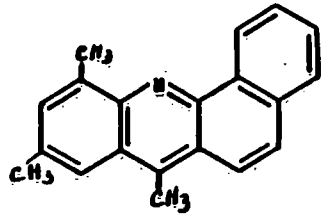
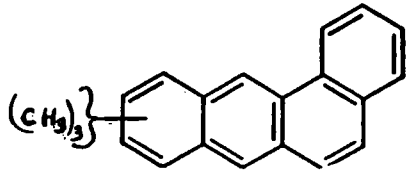
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Trimethylanthracene	-	3	$C_{17}H_{16}$	220	Sol Mg/l H_2O= M. P. = B. P. =	
8,10,12-trimethylbenz (a)-acridine	51787-43-0	4	$C_{20}H_{17}N$	271	Sol Mg/l H_2O= M. P. = B. P. =	
7,9,11-trimethylbenz (c)-acridine	51787-42-9	4	$C_{20}H_{17}N$	271	Sol Mg/l H_2O= M. P. = B. P. =	
Trimethylbenz (a)-anthracene	-	4	$C_{21}H_{18}$	270	Sol Mg/l H_2O= M. P. = B. P. =	

TABLE K3-1 (Continued)

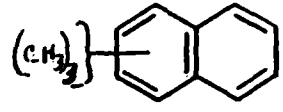
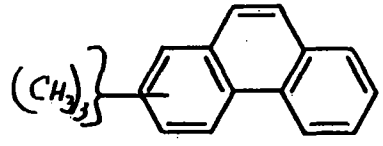
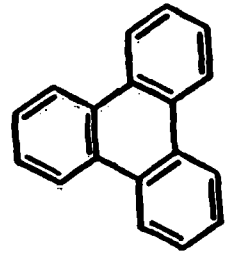
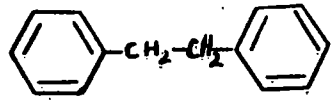
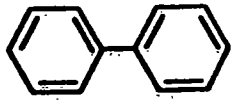
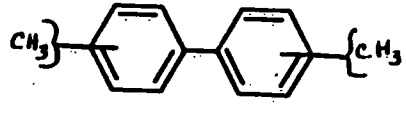
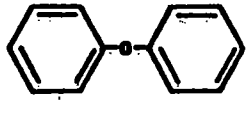
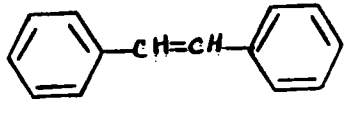
NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Timethylnaphthalenes		2	$C_{13}H_{14}$	170	Sol Mg/l H_2O= M. P. = B. P. =	
Trimethylphenanthrene		3	$C_{17}H_{16}$	220	Sol Mg/l H_2O= M. P. = B. P. =	
Triphenylene	217-59-4	4	$C_{18}H_{12}$	228	Sol Mg/l H_2O=0.043 M. P. =199°C B. P. =425°C	

TABLE K3-1 (Continued)

NAME	Reg. #	# Rings	Formula	Mol. Wt.	Phys. Prop.	STRUCTURE
Bibenzyl Dibenzyl 1,2-diphenylethane	103-29-7	2	$C_{14}H_{14}$	182	Sol Mg/l H_2O= M. P. =53°C B. P. =284°C	
Biphenyl Diphneyl phenylbenzene	92-15-8	2	$C_{12}H_{10}$	154	Sol Mg/l H_2O=7.0 M. P. =69°C B. P. =255°C	
Dimethylbiphenyl	-	2	$C_{14}C_{14}$	182	Sol Mg/l H_2O= M. P. = B. P. =	
Phenyl ether Diphenyloxide Diphenylether Biphenyloxide Biphenylether	101-84-8	2	$C_{12}H_{10}O$	170	Sol Mg/l H_2O= M. P. =27.5°C B. P. =259°C	
Stilbene Cis-Stilbene (isostilbene) trans-Stilbene	645-49-8 103-30-0	2 2	$C_{14}C_{12}$ $C_{14}C_{12}$	180 180	Sol Mg/l H_2O= M. P. =124°C B. P. =307°C	

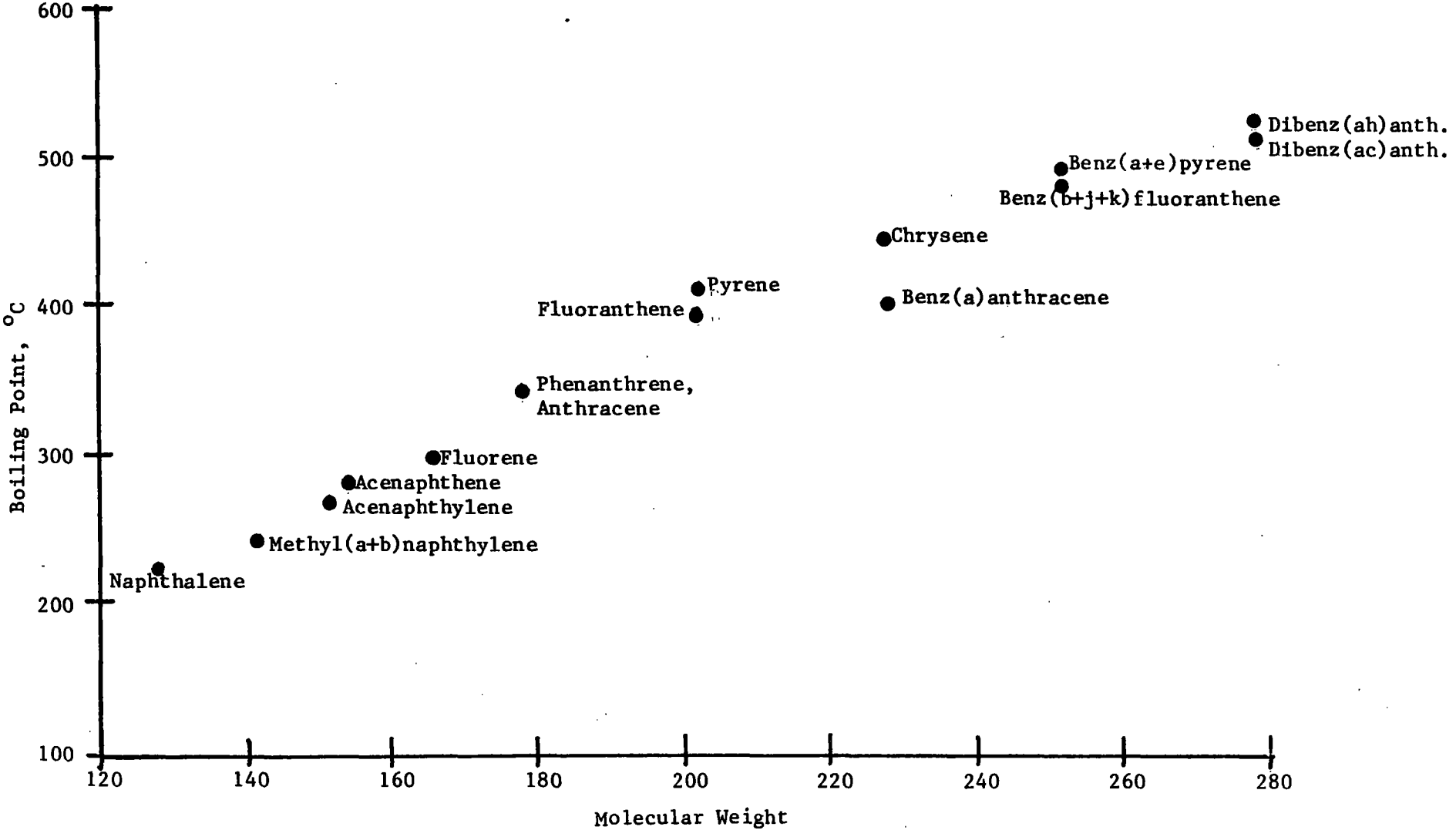


Figure K3-1 Boiling Point as a Function of Molecular Weight for PAH Compounds

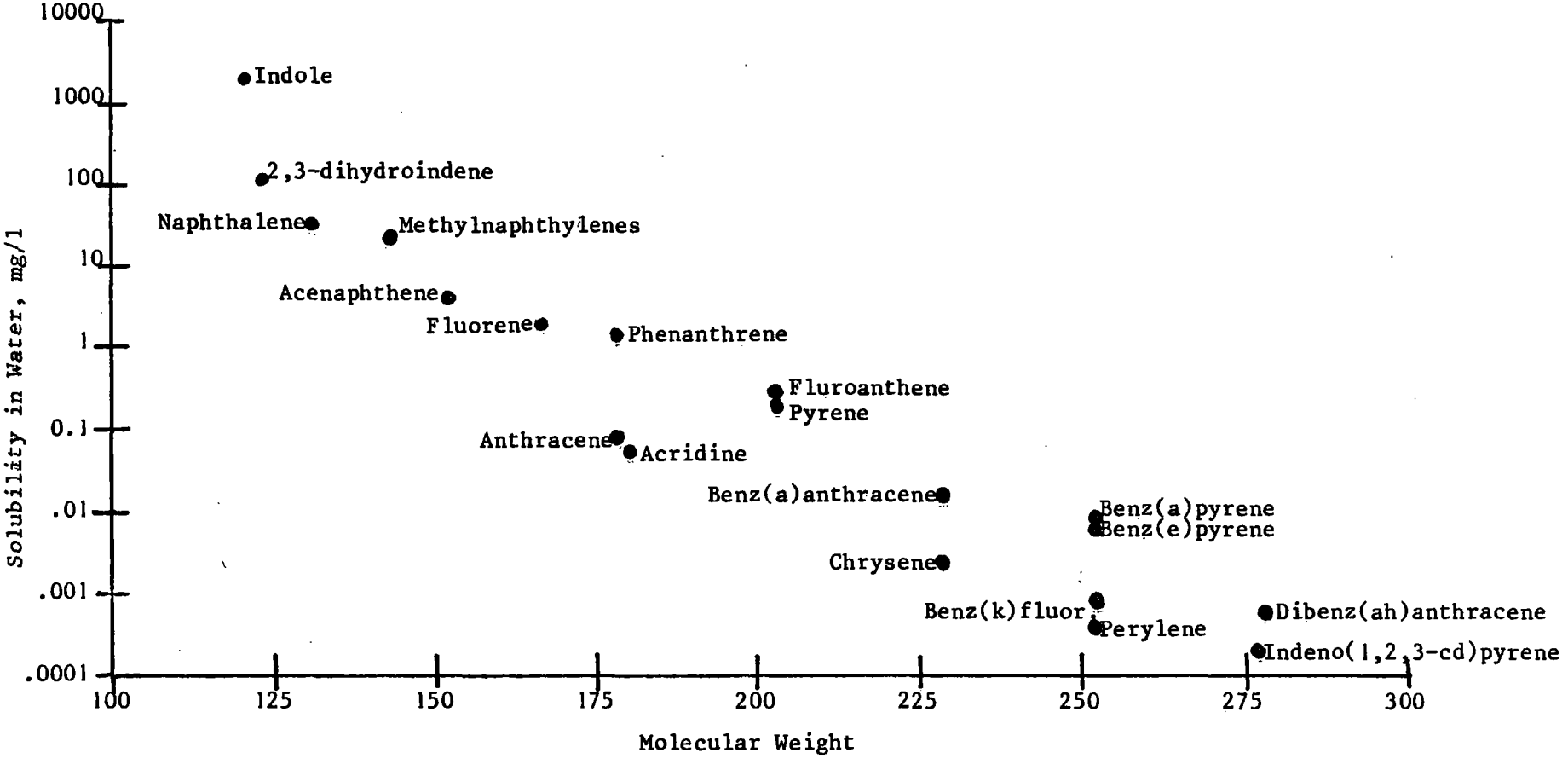


Figure K3-2 Solubility as a Function of Molecular Weight for PAH Compounds

TABLE K5-1

COMPOUNDS ANALYZED
BY PRINCIPAL LABORATORIES

	TOTAL PAH	MDH	CH2MHILL	CAPSULE	MRI	MRC	Serco
Acenaphthylene	X	X	X	X	X	X	X
Acenaphthene			X	X	X	X	X
Anthracene	X	X	X	X		X	X
Benzo(a)anthracene	X	X	X	X		X	X
Benzo(a)pyrene	X	X	X	X	X	X	X
Benzo(b)fluroanthene			X	X	X		X
Benzo(c)phenanthrene		X				X	
Benzo(e)pyrene		X	X				
Benzo(g h i)perylene	X	X	X	X	X	X	X
Benzo(j)fluoranthene		X					
Benzo(k)fluoranthene	X	X	X	X	X		X
Chrysene	X	X	X	X	X	X	X
Dibenzo(a,c)anthracene		X					
Dibenzo(a,h)anthracene			X	X	X		X
Fluorene	X	X	X	X	X	X	X
Fluoranthene	X	X	X	X	X	X	X
Indeno(1,2,3-cd)pyrene	X	X	X	X	X	X	X
Perylene		X	X			X	
Phenanthrene	X	X	X	X	X	X	X
Pyrene	X	X	X	X	X	X	X
4,5,9,10-tetrahydropyrene		X					
Acridine			X		X		
Benzo(b)thiophene			X				
Carbazole			X		X		
Indole			X		X		
Quinoline			X		X		
Biphenyl		X	X			X	
2,3-dihydroindene			X				
Indene			X				
1-methylnaphthalene			X			X	
2-methylnaphthalene		X	X			X	
Naphthalene			X	X	X	X	X
Phenanthridine			X				

TABLE K5-2

CARCINOGEN CLASSES OF GROUND-WATER DATA BASE COMPOUNDS

CARCINOGENS

Benzo(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(c)phenanthrene
Benzo(j)fluoranthene
Benzo(ghi)perylene
Chrysene
Dibenzo(a,c)anthracene
Dibenzo(a,h)anthracene
Dibenzo(a,e)pyrene
Dibenzo(a,h)pyrene
Dibenzo(a,i)pyrene
7,12-dimethylbenz(a)anthracene
Indeno(1,2,3-cd)pyrene
3-methylcholanthrene
Quinoline

NONCARCINOGENS

Acenaphthylene
Acenaphthene
Anthracene
Benzo(e)pyrene
Benzo(k)fluoranthene
Fluorene
Fluoranthene

TABLE K5-2

NONCARCINOGENS, Cont'd

Perylene
Phenanthrene
Pyrene
4,5,9,10-tetrahydropyrene
Triphenylene
Acridine
Benzo(b)thiophene
Benzofuran
Carbazole
Indole
Methylbenzofuran
Phenanthridine
Biphenyl
2,3-dihydroindene
Indene
1-Methylnaphthalene
2-Methylnaphthalene
Naphthalene

TABLE K5-3

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#03	780000	MDH	0.00	0.00
SLP#03	800129	MDH	30.00	36.01
SLP#03	800520	MDH	0.01	20.01
SLP#03	800703	MDH	0.01	0.95
SLP#03	810128	MDH	0.01	0.01
SLP#03	820115	CAPSULE	0.01	0.01
SLP#03	820331	CAPSULE	0.01	0.01
SLP#03	820500	CAPSULE	0.01	0.01
SLP#03	820500	CAPSULE	0.01	9.31
SLP#04	780000	MDH	0.00	4.50
SLP#04	790107	MDH	0.01	217.01
SLP#04	791019	MDH	3.60	435.80
SLP#04	791108	MDH	0.01	73.30
SLP#04	791116	MDH	7.40	363.90
SLP#04	791116	MDH	12.00	354.00
SLP#04	791116	MDH	0.01	348.40
SLP#04	791116	MDH	0.01	342.10
SLP#04	800107	MDH	2.41	312.01
SLP#04	800109	MDH	4.01	1075.81
SLP#04	800111	MDH	0.01	656.01

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#04	800114	MDH	0.01	565.01
SLP#04	800116	MDH	4.31	396.01
SLP#04	800118	MDH	4.51	259.01
SLP#04	800121	MDH	8.21	328.01
SLP#04	800123	MDH	3.71	810.01
SLP#04	800125	MDH	0.01	426.71
SLP#04	800128	MDH	0.01	566.01
SLP#04	800130	MDH	0.01	435.01
SLP#04	800201	MDH	0.01	546.31
SLP#04	800226	MDH	8.01	131.91
SLP#04	800310	MDH	9.91	207.21
SLP#04	800310	MDH	5.11	201.01
SLP#04	800324	MDH	0.01	35.51
SLP#04	800501	MDH	0.01	102.01
SLP#04	800509	MDH	2.81	85.27
SLP#04	800516	MDH	0.01	87.30
SLP#04	800520	MDH	0.01	512.61
SLP#04	800530	MDH	0.01	15.21
SLP#04	800605	MDH	0.01	82.31
SLP#04	800613	MDH	0.01	323.51

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#04	800620	MDH	0.01	369.01
SLP#04	800625	MDH	0.01	237.11
SLP#04	800627	MDH	0.01	111.71
SLP#04	800703	MDH	0.01	177.11
SLP#04	800707	MDH	0.01	180.11
SLP#04	800708	MDH	1.71	106.51
SLP#04	800709	MDH	0.01	228.21
SLP#04	800710	MDH	0.01	367.90
SLP#04	800711	MDH	0.01	154.31
SLP#04	800712	MDH	0.01	12.11
SLP#04	800713	MDH	0.01	94.81
SLP#04	800718	MDH	2.01	37.41
SLP#04	800721	MDH	7.81	210.80
SLP#04	800723	MDH	0.01	186.80
SLP#04	800724	MDH	18.30	175.90
SLP#04	800801	MDH	0.01	1.51
SLP#04	810000	EPA WHI	0.01	0.01
SLP#04	810128	MDH	0.01	26.61
SLP#04	810226	MRI	0.00	0.01
SLP#04	810226	MRI	2.00	1.00

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#04	810312	MRI	0.00	0.01
SLP#04	810312	MRI	0.00	0.01
SLP#04	810312	MRI	1316.00	416.00
SLP#04	810312	MRI	0.00	635.00
SLP#04	810723	MDH	0.01	96.01
SLP#04	810826	CH2MHIL	0.00	257.00
SLP#04	820115	CAPSULE	0.00	93.00
SLP#04	820115	CAPSULE	0.00	254.00
SLP#04	820331	CAPSULE	0.01	222.00
SLP#04	820500	CAPSULE	0.01	88.01
SLP#04	820503	CH2MHIL	1.00	395.00
SLP#04	820503	CH2MHIL	0.00	419.00
SLP#04	820503	CH2MHIL	3.00	445.00
SLP#04	820915	MRC	2.03	222.40
SLP#04	820915	CH2MHIL	0.01	525.51
SLP#04	820915	CH2MHIL	0.01	547.21
SLP#04	821030	CH2MHIL	0.01	782.61
SLP#04	821030	CH2MHIL	0.01	395.71
SLP#05	780000	MDH	0.00	7.40
SLP#05	800129	MDH	8.41	5.11

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#05	800703	MDH	0.01	1822.01
SLP#05	810128	MDH	0.01	17.71
SLP#05	810128	MDH	0.25	19.01
SLP#05	810206	MRI	0.00	0.01
SLP#05	810206	MRI	25.00	10.00
SLP#05	810213	MRI	0.00	0.01
SLP#05	810213	MRI	3.00	1.00
SLP#05	810226	MRI	0.00	0.01
SLP#05	810226	MRI	0.00	0.00
SLP#05	810723	MDH	15.00	29200.45
SLP#05	810817	MDH	32.01	5990.00
SLP#05	810817	CH2MHIL	146.00	5938.00
SLP#05	810817	CH2MHIL	21.00	9476.00
SLP#05	810817	CH2MHIL	18.00	8535.00
SLP#05	810817	CH2MHIL	0.00	15883.00
SLP#05	820713	CAPSULE	0.01	32.01
SLP#05	820714	CAPSULE	0.01	107.01
SLP#05	820909	MRC	3.41	95.00
SLP#05	820909	CH2MHIL	0.01	22926.01
SLP#05	821030	CH2MHIL	0.01	4806.91

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#06	780000	MDH	0.00	0.00
SLP#06	791019	MDH	0.01	0.01
SLP#06	800107	MDH	0.01	15.01
SLP#06	800109	MDH	0.01	21.41
SLP#06	800111	MDH	0.01	21.21
SLP#06	800114	MDH	0.01	7.71
SLP#06	800116	MDH	0.01	19.41
SLP#06	800118	MDH	0.01	38.01
SLP#06	800121	MDH	1.01	26.01
SLP#06	800123	MDH	4.61	58.01
SLP#06	800125	MDH	0.01	45.71
SLP#06	800128	MDH	11.01	0.01
SLP#06	800130	MDH	8.91	121.01
SLP#06	800201	MDH	0.01	0.01
SLP#06	800201	MDH	0.01	0.01
SLP#06	800226	MDH	3.91	12.59
SLP#06	800310	MDH	0.01	15.31
SLP#06	800310	MDH	0.01	24.01
SLP#06	800324	MDH	0.01	5.81
SLP#06	800520	MDH	0.01	33.11

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#06	800703	MDH	1.01	10.41
SLP#06	810128	MDH	0.01	1.31
SLP#06	810128	MDH	0.01	1.01
SLP#06	810206	MRI	0.00	0.01
SLP#06	810206	MRI	76.00	200.00
SLP#06	810213	MRI	0.00	0.01
SLP#06	810213	MRI	0.00	0.00
SLP#06	810226	MRI	0.00	0.01
SLP#06	810226	MRI	4.00	0.00
SLP#06	820115	CAPSULE	0.01	0.01
SLP#06	820331	CAPSULE	0.01	0.01
SLP#06	820500	CAPSULE	0.01	5.31
SLP#06	820500	CAPSULE	0.01	0.01
SLP#06	820800	CAPSULE	0.01	0.01
SLP#07	780000	MDH	0.00	122.80
SLP#07	790000	USGS 79	1.00	220.00
SLP#07	791105	MDH	0.01	0.01
SLP#07	800108	MDH	0.01	213.01
SLP#07	800122	MDH	11.01	194.21
SLP#07	800205	MDH	0.01	88.21

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#07	800605	MDH	0.01	84.91
SLP#07	800613	MDH	0.01	34.81
SLP#07	800620	MDH	4.11	64.51
SLP#07	800627	MDH	0.01	105.91
SLP#07	800703	MDH	0.01	188.31
SLP#07	800704	MDH	0.01	51.11
SLP#07	800707	MDH	0.01	173.31
SLP#07	800708	MDH	0.01	182.41
SLP#07	800709	MDH	0.01	63.91
SLP#07	800710	MDH	0.01	156.41
SLP#07	800711	MDH	25.01	122.81
SLP#07	800712	MDH	0.01	60.11
SLP#07	800713	MDH	0.01	248.70
SLP#07	800718	MDH	7.81	200.11
SLP#07	800721	MDH	0.01	111.61
SLP#07	800723	MDH	0.00	168.61
SLP#07	800724	MDH	0.00	160.70
SLP#07	800727	MDH	0.00	37.31
SLP#07	800801	MDH	0.01	100.00
SLP#07	810723	MDH	2.41	475.80

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#07	810826	CH2MHIL	0.00	0.00
SLP#07	820500	CAPSULE	0.01	9.51
SLP#07	820915	MRC	2.71	120.90
SLP#07	820915	CH2MHIL	0.01	149.21
SLP#07	821030	CH2MHIL	0.01	112.31
SLP#08	780000	MDH	0.00	0.00
SLP#08	791019	MDH	0.01	5.81
SLP#08	800129	MDH	0.01	1.01
SLP#08	800520	MDH	0.01	9.41
SLP#08	800703	MDH	17.01	45.11
SLP#08	810128	MDH	0.01	0.01
SLP#08	810226	MRI	0.00	0.01
SLP#08	810226	MRI	0.00	0.00
SLP#08	820115	CAPSULE	0.01	0.01
SLP#08	820331	CAPSULE	0.01	0.01
SLP#08	820500	CAPSULE	0.01	0.01
SLP#08	820500	CAPSULE	0.01	0.01
SLP#08	820800	CAPSULE	0.01	0.01
SLP#09	780000	MDH	0.00	232.30
SLP#09	790000	USGS 79	1.00	325.00

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#09	791105	MDH	0.01	0.01
SLP#09	800605	MDH	0.01	29.85
SLP#09	800613	MDH	0.01	55.21
SLP#09	800620	MDH	0.01	75.61
SLP#09	800627	MDH	2.81	96.81
SLP#09	800703	MDH	0.01	120.81
SLP#09	800704	MDH	0.01	23.31
SLP#09	800707	MDH	0.01	93.11
SLP#09	800708	MDH	0.01	97.91
SLP#09	800709	MDH	9.51	72.31
SLP#09	800710	MDH	0.01	148.01
SLP#09	800711	MDH	0.01	138.71
SLP#09	800712	MDH	0.01	46.21
SLP#09	800713	MDH	1.61	232.40
SLP#09	800718	MDH	0.01	271.71
SLP#09	800721	MDH	6.61	86.71
SLP#09	800723	MDH	0.01	3.71
SLP#09	800724	MDH	0.01	224.20
SLP#09	800727	MDH	2.50	123.00
SLP#09	800801	MDH	2.20	1.01

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#09	810826	CH2MHIL	0.00	4.00
SLP#09	820909	MRC	1.71	212.60
SLP#09	820909	CH2MHIL	0.01	107.31
SLP#09	821030	CH2MHIL	0.01	65.61
SLP#09	821107	CH2MHIL	0.01	120.11
SLP#10	780000	MDH	0.00	1350.00
SLP#10	780000	MDH	5.70	692.00
SLP#10	790000	USGS 79	1.00	970.00
SLP#10	791105	MDH	109.00	2430.00
SLP#10	800129	MDH	200.00	3414.91
SLP#10	800703	MDH	95.00	6158.01
SLP#10	810226	MRI	0.00	0.01
SLP#10	810226	MRI	20.00	615.00
SLP#11	780000	MDH	0.00	0.00
SLP#11	791019	MDH	0.01	0.01
SLP#11	800129	MDH	8.51	504.01
SLP#11	800324	MDH	0.01	4.61
SLP#11	800520	MDH	0.01	0.52
SLP#11	800703	MDH	19.01	47.91
SLP#11	810128	MDH	0.01	0.01

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#11	810226	MRI	0.00	0.01
SLP#11	810226	MRI	3.00	1100.00
SLP#11	820115	CAPSULE	0.01	0.01
SLP#11	820500	CAPSULE	0.01	33.01
SLP#12	780000	MDH	0.00	0.00
SLP#12	791019	MDH	0.01	0.01
SLP#12	800129	MDH	0.01	85.01
SLP#12	800520	MDH	0.01	31.21
SLP#12	800703	MDH	0.01	0.74
SLP#12	810128	MDH	0.01	81.84
SLP#12	820115	CAPSULE	0.01	0.01
SLP#12	820500	CAPSULE	0.01	18.01
SLP#13	780000	MDH	0.00	1.00
SLP#13	780000	MDH	0.00	0.00
SLP#13	791019	MDH	0.01	0.01
SLP#13	800108	MDH	0.01	6.11
SLP#13	800122	MDH	3.61	14.41
SLP#13	800206	MDH	1.01	0.01
SLP#13	800703	MDH	0.01	33.87
SLP#13	810128	MDH	0.01	0.01

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#13	820115	CAPSULE	0.01	0.01
SLP#13	820500	CAPSULE	0.01	80.01
SLP#14	780000	MDH	9.50	10.50
SLP#14	780000	MDH	5.40	8.70
SLP#14	790000	USGS 79	1.20	30.00
SLP#14	791019	MDH	0.01	62.00
SLP#14	800129	MDH	0.01	145.01
SLP#14	800226	MDH	2.81	22.41
SLP#14	800310	MDH	14.31	55.91
SLP#14	800310	MDH	0.01	40.81
SLP#14	800324	MDH	9.41	98.61
SLP#14	800520	MDH	0.01	33.31
SLP#14	800703	MDH	0.01	192.00
SLP#14	810128	MDH	0.01	264.91
SLP#14	810401	MDH	6.21	70.71
SLP#14	810723	MDH	2.71	398.11
SLP#14	811107	CAPSULE	0.01	0.01
SLP#14	820115	CAPSULE	0.01	79.01
SLP#14	820115	CAPSULE	0.01	11.01
SLP#14	820331	CAPSULE	0.01	49.01

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#14	820500	CAPSULE	0.01	9.21
SLP#14	820500	CAPSULE	0.01	54.01
SLP#14	820800	CAPSULE	0.01	24.21
SLP#15	780000	MDH	0.00	1330.00
SLP#15	780000	MDH	10.30	1754.00
SLP#15	790000	EPA WHI	0.01	1051.00
SLP#15	790000	USGS 79	0.20	1600.00
SLP#15	790716	MDH	0.01	5410.00
SLP#15	790718	MDH	0.01	4640.00
SLP#15	790719	MDH	0.01	5080.00
SLP#15	790720	MDH	0.00	2200.00
SLP#15	791019	MDH	39.00	2130.00
SLP#15	791105	MDH	109.00	2430.00
SLP#15	791108	MDH	70.00	2750.00
SLP#15	800129	MDH	115.01	3550.01
SLP#15	800605	MDH	26.01	4090.01
SLP#15	800613	MDH	41.11	5910.01
SLP#15	800620	MDH	48.01	3240.01
SLP#15	800627	MDH	26.81	5120.01
SLP#15	800703	MDH	0.01	2684.01

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#15	800711	MDH	52.91	820.01
SLP#15	800801	MDH	0.01	6.41
SLP#15	810130	MDH	0.75	25730.01
SLP#15	810226	MRI	0.00	6800.00
SLP#15	810312	MRI	0.00	10600.00
SLP#15	810600	CH2MHIL	0.00	1050.00
SLP#15	810826	CH2MHIL	9.00	4376.00
SLP#15	811107	CAPSULE	0.01	121.50
SLP#15	820115	CAPSULE	28.00	1698.00
SLP#15	820115	CAPSULE	0.00	790.00
SLP#15	820300	CH2MHIL	17.00	47470.00
SLP#15	820300	CH2MHIL	10.00	6850.00
SLP#15	820331	CAPSULE	25.01	2290.00
SLP#15	820915	MRC	14.40	2803.70
SLP#15	820915	MRC	18.60	2893.60
SLP#15	820915	MRC	9.90	177.40
SLP#15	820915	CH2MHIL	0.01	9312.01
SLP#15	821107	CH2MHIL	29.01	10232.00
SLP#15	821112	CH2MHIL	23.01	9533.00
SLP#15	821203	CH2MHIL	47.00	9644.00

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-3 (Continued)

SLP MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
SLP#15	821207	CH2MHIL	31.20	6879.40
SLP#15	821207	CH2MHIL	28.20	7549.00
SLP#16	780000	MDH	0.00	0.00
SLP#16	791019	MDH	0.01	6.00
SLP#16	800129	MDH	3.71	0.01
SLP#16	800520	MDH	0.01	0.55
SLP#16	800703	MDH	0.00	0.00
SLP#16	810128	MDH	0.01	0.01
SLP#16	820115	CAPSULE	0.01	0.01
SLP#16	820331	CAPSULE	0.01	0.01
SLP#16	820500	CAPSULE	0.01	4.81
SLP#16	820500	CAPSULE	0.01	0.01
SLP#16	820800	CAPSULE	0.01	0.01

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-4

HOPKINS MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
HOPKN#01	790531	MDH	0.01	15.41
HOPKN#01	800117	MDH	48.11	41.41
HOPKN#01	800618	MDH	0.01	29.21
HOPKN#01	810130	MDH	0.01	2.11
HOPKN#01	810225	MRI	0.00	0.01
HOPKN#01	810225	MDH	0.01	1.61
HOPKN#01	810304	MDH	0.01	20.51
HOPKN#01	810311	MDH	1.11	0.74
HOPKN#01	810804	SERCO	6.00	0.00
HOPKN#01	810826	SERCO	85.00	0.00
HOPKN#01	810922	SERCO	0.00	0.00
HOPKN#01	811019	SERCO	0.00	0.00
HOPKN#01	811130	SERCO	0.00	0.00
HOPKN#01	811218	SERCO	0.01	0.01
HOPKN#03	790531	MDH	0.73	38.21
HOPKN#03	790531	MDH	0.91	21.61
HOPKN#03	810130	MDH	0.01	4685.11
HOPKN#03	810225	MRI	0.00	400.01
HOPKN#03	810225	MDH	0.60	10319.41
HOPKN#03	810225	MDH	1.11	10794.01

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-4 (Continued)

HOPKINS MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
HOPKN#03	810304	MDH	7.91	5097.91
HOPKN#03	810304	MDH	1.91	4978.91
HOPKN#03	810311	MDH	0.01	290.01
HOPKN#03	810311	MDH	0.01	219.51
HOPKN#03	810318	MDH	0.01	115.91
HOPKN#03	810318	MDH	0.01	143.31
HOPKN#03	810804	SERCO	7.00	151.00
HOPKN#03	810826	SERCO	6.00	1618.00
HOPKN#03	810922	SERCO	0.00	0.00
HOPKN#03	811019	SERCO	0.00	0.00
HOPKN#03	811130	SERCO	0.00	180.00
HOPKN#03	811218	SERCO	0.01	40.01
HOPKN#03	820909	MRC	2.30	91.41
HOPKN#03	820909	CH2MHIL	0.01	78.41
HOPKN#03	821030	CH2MHIL	0.01	158.81
HOPKN#04	790531	MDH	0.01	294.81
HOPKN#04	800117	MDH	0.01	46.01
HOPKN#04	800304	MDH	0.01	69.41
HOPKN#04	800618	MDH	0.01	1.51
HOPKN#04	810130	MDH	0.01	0.01

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-4 (Continued)

HOPKINS MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
HOPKN#04	810311	MDH	0.01	1.91
HOPKN#04	810318	MDH	0.63	2.25
HOPKN#04	810804	SERCO	5.00	17.00
HOPKN#04	810826	SERCO	0.00	0.00
HOPKN#04	810922	SERCO	0.00	0.00
HOPKN#04	811019	SERCO	0.00	0.00
HOPKN#04	811130	SERCO	0.00	0.00
HOPKN#04	811218	SERCO	0.01	0.01
HOPKN#05	790531	MDH	2.60	17.91
HOPKN#05	800117	MDH	0.01	14.01
HOPKN#05	800304	MDH	0.01	32.41
HOPKN#05	800618	MDH	0.01	9.41
HOPKN#05	810225	MDH	3.81	0.76
HOPKN#05	810304	MDH	1.00	88.61
HOPKN#05	810311	MDH	0.01	2.91
HOPKN#05	810318	MDH	0.90	2.31
HOPKN#05	810804	SERCO	3.00	7.00
HOPKN#05	810826	SERCO	8.00	0.00
HOPKN#05	810922	SERCO	0.00	0.00
HOPKN#05	811019	SERCO	0.00	0.00

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-4 (Continued)

HOPKINS MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
HOPKN#05	811130	SERCO	0.00	0.00
HOPKN#05	811218	SERCO	0.01	0.01
HOPKN#06	790531	MDH	0.01	12.43
HOPKN#06	800304	MDH	11.81	31.41
HOPKN#06	800304	MDH	0.01	13.21
HOPKN#06	800618	MDH	0.01	13.83
HOPKN#06	810225	MDH	2.71	1.62
HOPKN#06	810304	MDH	0.01	1.51
HOPKN#06	810311	MDH	0.01	2.74
HOPKN#06	810318	MDH	0.01	1.01
HOPKN#06	810804	SERCO	52.00	75.00
HOPKN#06	810826	SERCO	75.00	0.00
HOPKN#06	810922	SERCO	0.00	0.00
HOPKN#06	811019	SERCO	0.00	0.00
HOPKN#06	811130	SERCO	0.00	0.00
HOPKN#06	811218	SERCO	0.00	0.00

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-5

EDINA MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
EDINA#02	780000	MDH	0.00	3.10
EDINA#02	790109	MDH	0.00	12.60
EDINA#02	790522	MDH	4.51	11.90
EDINA#02	790522	MDH	3.51	5.91
EDINA#02	800108	MDH	2.01	16.61
EDINA#02	800122	MDH	0.01	15.01
EDINA#02	800205	MDH	0.01	3.91
EDINA#02	800226	MDH	0.01	11.48
EDINA#02	800310	MDH	0.01	24.31
EDINA#02	800310	MDH	0.01	37.71
EDINA#02	800325	MDH	0.01	15.31
EDINA#02	800626	MDH	1.01	2.23
EDINA#02	800801	MDH	0.01	0.94
EDINA#02	810129	MDH	0.01	5.81
EDINA#02	810129	MDH	0.01	2.01
EDINA#02	810227	MRI	0.00	0.01
EDINA#02	810227	MRI	6.00	333.00
EDINA#02	810812	MDH	0.01	5.81
EDINA#03	780000	MDH	0.00	1.00
EDINA#03	790522	MDH	7.31	10.00

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-5 (Continued)

EDINA MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
EDINA#03	800626	MDH	0.01	44.11
EDINA#03	800801	MDH	0.01	0.01
EDINA#04	780000	MDH	0.00	0.90
EDINA#04	790109	MDH	0.00	10.50
EDINA#04	790522	MDH	43.00	32.60
EDINA#04	800108	MDH	12.01	6.01
EDINA#04	800122	MDH	0.01	0.01
EDINA#04	800205	MDH	0.01	0.01
EDINA#04	800226	MDH	0.01	46.31
EDINA#04	800310	MDH	0.01	23.01
EDINA#04	800310	MDH	0.01	10.01
EDINA#04	800325	MDH	0.01	34.21
EDINA#04	800626	MDH	0.01	1.11
EDINA#04	800801	MDH	0.01	2.21
EDINA#05	800801	MDH	0.01	1.11
EDINA#06	790109	MDH	0.00	2.35
EDINA#06	790522	MDH	0.01	3.00
EDINA#06	800108	MDH	11.01	9.21
EDINA#06	800122	MDH	0.01	0.01
EDINA#06	800205	MDH	0.02	0.01

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-5 (Continued)

EDINA MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
EDINA#06	800226	MDH	0.01	4.11
EDINA#06	800310	MDH	0.94	13.81
EDINA#06	800310	MDH	0.01	18.71
EDINA#06	800325	MDH	0.01	21.51
EDINA#06	800626	MDH	0.01	0.01
EDINA#06	800801	MDH	0.01	0.01
EDINA#06	810129	MDH	0.01	0.01
EDINA#06	810227	MRI	0.00	0.01
EDINA#06	810227	MRI	0.00	573.00
EDINA#07	780000	MDH	0.00	0.00
EDINA#07	790522	MDH	4.61	8.18
EDINA#07	800626	MDH	0.01	12.91
EDINA#07	810812	MDH	2.00	2.28
EDINA#08	800801	MDH	0.01	0.01
EDINA#10	790109	MDH	0.43	4.40
EDINA#10	800115	MDH	0.01	17.91
EDINA#10	800801	MDH	0.01	0.49
EDINA#11	790109	MDH	0.00	9.49
EDINA#11	790109	MDH	0.00	9.85
EDINA#11	800115	MDH	0.01	2.01

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-5 (Continued)

EDINA MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
EDINA#11	800801	MDH	0.01	0.01
EDINA#12	790109	MDH	0.00	2.50
EDINA#12	790522	MDH	2.31	5.71
EDINA#12	790522	MDH	3.21	8.04
EDINA#12	800801	MDH	0.01	0.01
EDINA#13	790109	MDH	0.00	1.40
EDINA#13	790522	MDH	4.31	8.97
EDINA#13	800115	MDH	0.01	3.01
EDINA#13	800626	MDH	0.01	0.66
EDINA#13	800801	MDH	3.10	1.61
EDINA#13	810812	MDH	0.01	1.23
EDINA#14	800801	MDH	0.01	0.01
EDINA#15	780000	MDH	0.00	0.00
EDINA#15	790522	MDH	4.71	8.43
EDINA#15	800626	MDH	1.41	1.01
EDINA#15	800801	MDH	0.00	0.01
EDINA#15	810812	MDH	6.41	28.00
EDINA#16	790109	MDH	0.00	6.22
EDINA#16	800115	MDH	0.01	28.31
EDINA#16	800801	MDH	0.00	0.01

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-5 (Continued)

EDINA MUNICIPAL WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
EDINA#16	810227	MRI	0.00	0.01
EDINA#16	810227	MRI	0.00	0.01
EDINA#16	810227	MRI	0.00	293.00
EDINA#16	810227	MRI	0.00	293.00
EDINA#17	780000	MDH	0.00	0.00
EDINA#17	800626	MDH	0.01	36.81
EDINA#18	800801	MDH	0.01	0.01

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-6

MONITOR. & PRIVATE WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
ACE MFG	790209	MDH	422.80	2725.21
ADM	700515	MDH	8.10	37.41
ANDROC	790220	MDH	0.01	26.51
BECK PRO	810213	MRI	0.00	0.01
BECK PRO	810213	MRI	220.00	805.00
BRD GRN	790405	MDH	0.01	0.01
CRIB-DIA	790424	MDH	2.40	88.01
DAY RG#2	790000	USGS 79	0.00	902.50
DAY RG#2	790209	MDH	0.01	862.23
DAY#3	810223	MRI	0.00	0.01
DAY#3	810223	MRI	213000.00	94000.00
EIT HSP	810224	MRI	0.00	0.01
EIT HSP	810224	MRI	37.00	90.00
FLAME	790522	MDH	492.40	83917.90
FLAME	791017	MDH	250.00	8400.00
FLAME	810000	EPA WHI	0.01	50.01
FLAME	810312	MRI	0.00	2400.01
HEDBRG#1	790815	MDH	132.00	770.00
HEDBRG#2	790801	MDH	0.01	87.00
MERIT	790206	MDH	8.70	52.69

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-6 (Continued)

MONITOR. & PRIVATE WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
MINN RBR	810210	MRI	0.00	0.01
MINN RBR	810210	MRI	0.00	249.00
MINN RBR	810213	MRI	0.00	0.01
MINN RBR	810213	MRI	0.00	756.00
MON.W001	810206	MRI	0.00	450.01
MON.W002	800630	CH2MHIL	12.00	8.00
MON.W002	810206	MRI	0.00	690.01
MON.W002	820908	CH2MHIL	0.01	36.61
MON.W002	821103	CH2MHIL	0.01	19.01
MON.W006	790000	USGS 79	1000000.00	12400000.00
MON.W010	790000	USGS 79	0.00	3100.01
MON.W011	790000	USGS 79	100.00	4000.00
MON.W013	810312	MRI	200000000.00	3400000000
MON.W013	810600	CH2MHIL	8000000.00	554000000
MON.W013	810600	CH2MHIL	595000000.00	1946000000
MON.W013	820909	CH2MHIL	161000000.00	2374000000
MON.W016	790000	USGS 79	0.00	100.01
MON.W017	790000	USGS 79	0.00	15000.00
MON.W019	790000	USGS 79	6.00	12.50
MON.W020	790000	USGS 79	4.00	36.80

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-6 (Continued)

MONITOR. & PRIVATE WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
MON.W038	810224	MRI	0.00	3500.01
MON.W100	790000	USGS 79	1.00	61.80
MON.W100	800630	CH2MHIL	0.00	6.70
MON.W100	800715	CH2MHIL	3.90	1.00
MON.W100	820908	CH2MHIL	0.01	0.02
MON.W100	821103	CH2MHIL	3.50	21.61
MON.W101	790000	USGS 79	1.00	1041.00
MON.W101	810206	MRI	0.00	5540.01
MON.W115	790000	USGS 79	0.00	161.10
MON.W116	810206	MRI	0.00	0.01
MON.W117	790000	EPA WHI	0.01	4930.01
MON.W117	810206	MRI	0.00	2500.01
MON.W117	810311	MRI	0.00	3000.01
MON.W124	810206	MRI	0.00	0.01
MON.W124	810206	MRI	0.00	0.01
MON.W124	810206	MRI	51.00	485.00
MON.W133	810206	MRI	0.00	0.01
MON.W133	810206	MRI	62.00	672.00

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-6 (Continued)

MONITOR. & PRIVATE WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
METH HSP	800606	MDH	4.31	2516.51
METH HSP	800711	MDH	9.81	404.62
MIL RR	800109	MDH	10650.01	42460.01
OSLP#01	800627	CH2MHIL	10.80	79.20
OSLP#01	810219	MRI	0.00	0.01
OSLP#01	810219	MRI	0.00	0.00
OSLP#01	820909	CH2MHIL	0.01	245.72
OSLP#01	821103	CH2MHIL	0.01	345.01
PARK PET	790522	MDH	2.40	80.81
PARK TH	790607	MDH	24.00	9470.01
PARK TH	820909	MRC	13.70	1538.10
PARK TH	820909	CH2MHIL	0.01	3364.41
PARK TH	821103	CH2MHIL	16.61	3179.91
PRESTLT	790816	MDH	106.00	205.00
PROF INS	790426	MDH	2.40	3.61
PRUD INS	810213	MRI	0.00	0.01
PRUD INS	810213	MRI	0.00	572.00

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-6 (Continued)

MONITOR. & PRIVATE WELLS

GROUND-WATER DATA
TOTALS BY CARCINOGENS AND NONCARCINOGENS

WELL CODE	SAMPLE DATE	REPORT ID	TOTAL CARCINOGENS	TOTAL NONCARCINOGENS
RED OWL	810812	MDH	0.01	10.61
SITE-W23	810219	MRI	14001.00	314000.00
STRAND	790605	MDH	6.60	4.11
TERRY EX	790717	MDH	0.01	7995.00
TXTNK SC	790815	MDH	475.00	20200.00
WEISMAN	800014	MDH	187.51	1526.71
WELL 030	790426	MDH	0.01	70.01
WELL 030	790514	MDH	7.60	189.40
WELL 060	790613	MDH	23.50	20.51
WLWD N.	810227	MRI	0.00	0.01
WLWD N.	810227	MRI	0.00	2710.00

ALL VALUES ARE IN PPT
CARCINOGEN CRITERION = 28 PPT
NONCARCINOGEN CRITERION RANGE = 4000-400,000 PPT

NO LESS THAN VALUES ARE INCLUDED IN THE TOTALS

TABLE K5-7

PHENOLICS CONCENTRATION IN GROUND-WATER SAMPLES

WELL CODE	SAMPLE DATE	REPORT ID	METHOD	PHENOL PPM
BECK PRO	810213	MRI	GC/MS	0.001
BRN GRN	740100	BARR	4AMINO	0.001
BRN GRN	740200	BARR	MBTH	0.017
BRN GRN	760915	BARR	4AMINO	0.001
CRIB-DIA	760915	BARR	4AMINO	0.001
DAY RG#2	790000	USGS 79		0.010
DAY#3	810223	MRI	GC/MS	0.001
EDINA#02	810227	MRI	GC/MS	0.001
EDINA#06	810227	MRI	GC/MS	0.001
EDINA#16	810227	MRI	GC/MS	0.001
EDINA#16	810227	MRI	GC/MS	0.001
EIT HSP	810224	MRI	GC/MS	0.001
FLAME	731200	BARR	4AMINO	0.002
FLAME	740200	BARR	MBTH	0.004
FLAME	760401	BARR	4AMINO	0.001
FLAME	770526	BARR	4AMINO	0.004
FLAME	770526	BARR	MBTH	0.003
FLAME	770609	BARR	4AMINO	0.001
FLAME	810312	MRI	GC/MS	0.001
HARTMAN#	760924	BARR	4AMINO	0.002
HONWL#01	810227	MRI	GC/MS	0.001
HOPKN#01	810225	MRI	GC/MS	0.001
HOPKN#03	810225	MRI	GC/MS	0.001

TABLE K5-7 (Continued)

PHENOLICS CONCENTRATION IN GROUND-WATER SAMPLES

WELL CODE	SAMPLE DATE	REPORT I.D	METHOD	PHENOL PPM
L HARR#2	810223	MRI	GC/MS	0.001
METH HSP	760915	BARR	4AMINO	0.001
MHAHA	690900	HICKOK	X	0.020
MHAHA	690900	HICKOK	X	0.021
MINN RBR	731200	BARR	4AMINO	0.001
MINN RBR	740200	BARR	MBTH	0.009
MINN RBR	760915	BARR	4AMINO	0.001
MINN RBR	810210	MRI	GC/MS	0.001
MINN RBR	810213	MRI	GC/MS	0.001
MINNPK#	810211	MRI	GC/MS	0.001
MNNTK#11	810225	MRI	GC/MS	0.001
MNNTK#12	810225	MRI	GC/MS	0.001
MNNTK#13	810225	MRI	GC/MS	0.001
MNNTK#14	810225	MRI	GC/MS	0.001
MNNTK#14	810225	MRI	GC/MS	0.001
MON.W001	760412	BARR	4AMINO	0.001
MON.W001	770526	BARR	4AMINO	0.001
MON.W001	770526	BARR	MBTH	0.001
MON.W001	810206	MRI	GC/MS	0.001
MON.W002	760412	BARR	MBTH	0.001
MON.W002	770526	BARR	MBTH	0.001
MON.W002	770526	BARR	MBTH	0.001
MON.W002	810206	MRI	GC/MS	0.001
MON.W003	760526	BARR	4AMINO	0.001

TABLE K5-7 (Continued)

PHENOLICS CONCENTRATION IN GROUND-WATER SAMPLES

WELL CODE	SAMPLE DATE	REPORT ID	METHOD	PHENOL PPM
MON.W005	760408	BARR	4AMINO	0.153
MON.W005	770526	BARR	4AMINO	0.022
MON.W005	770526	BARR	MBTH	0.035
MON.W005	770602	BARR	4AMINO	0.028
MON.W006	760408	BARR	4AMINO	0.043
MON.W006	770526	BARR	4AMINO	0.088
MON.W006	770526	BARR	MBTH	0.190
MON.W006	770602	BARR	4AMINO	0.050
MON.W006	790000	USGS 79		0.100
MON.W007	760406	BARR	4AMINO	0.001
MON.W008	760406	BARR	4AMINO	0.001
MON.W008	770526	BARR	MBTH	0.001
MON.W008	770526	BARR	MBTH	0.001
MON.W009	700401	BARR	4AMINO	3.000
MON.W009	770218	BARR	4AMINO	0.760
MON.W009	770526	BARR	MBTH	0.600
MON.W009	770526	BARR	4AMINO	1.100
MON.W009	770602	BARR	4AMINO	0.600
MON.W010	760401	BARR	4AMINO	0.001
MON.W010	760526	BARR	4AMINO	0.004
MON.W010	760526	BARR	MBTH	17.000
MON.W010	790000	USGS 79		0.006
MON.W011	760526	BARR	4AMINO	0.004
MON.W011	760526	BARR	MBTH	0.023

TABLE K5-7 (Continued)

PHENOLICS CONCENTRATION IN GROUND-WATER SAMPLES

WELL CODE	SAMPLE DATE	REPORT ID	METHOD	PHENOL PPM
MON.W011	761209	BARR	4AMINO	0.022
MON.W011	790000	USGS 79		0.004
MON.W012	761210	BARR	4AMINO	0.014
MON.W013	770218	BARR	4AMINO	4.800
MON.W013	770526	BARR	4AMINO	51.000
MON.W013	770526	BARR	MBTH	56.000
MON.W013	770602	BARR	4AMINO	49.000
MON.W013	770622	BARR	4AMINO	50.000
MON.W013	810312	MRI	GC/MS	0.001
MON.W014	770218	BARR	4AMINO	0.001
MON.W014	770526	BARR	4AMINO	0.001
MON.W014	770526	BARR	MBTH	0.007
MON.W015	770526	BARR	4AMINO	0.028
MON.W015	770526	BARR	MBTH	0.037
MON.W016	770419	BARR	4AMINO	0.022
MON.W016	770526	BARR	4AMINO	0.004
MON.W016	770526	BARR	MBTH	0.001
MON.W016	790000	USGS 79		0.001
MON.W017	770419	BARR	4AMINO	0.280
MON.W017	770526	BARR	4AMINO	0.140
MON.W017	770526	BARR	MBTH	0.340
MON.W017	770602	BARR	4AMINO	0.180
MON.W017	770622	BARR	4AMINO	0.032
MON.W017	790000	USGS 79		0.200

TABLE K5-7 (Continued)

PHENOLICS CONCENTRATION IN GROUND-WATER SAMPLES

WELL CODE	SAMPLE DATE	REPORT ID	METHOD	PHENOL PPM
MON.W019	790000	USGS 79		0.010
MON.W020	790000	USGS 79		0.040
MON.W038	810224	MRI	GC/MS	0.001
MON.W100	790000	USGS 79		0.001
MON.W101	790000	USGS 79		0.020
MON.W101	810206	MRI	GC/MS	0.001
MON.W115	790000	USGS 79		0.010
MON.W116	810206	MRI	GC/MS	0.001
MON.W117	810206	MRI	GC/MS	0.001
MON.W117	810311	MRI	GC/MS	0.001
MON.W124	810206	MRI	GC/MS	0.001
MON.W124	810206	MRI	GC/MS	0.001
MON.W133	810206	MRI	GC/MS	0.001
MON.W001	770526	BARR	MBTH	0.002
NAT LED	810219	MRI	GC/MS	0.001
NAT LED	810219	MRI	GC/MS	0.001
NHOSP#02	810213	MRI	GC/MS	0.001
NHOSP#02	810213	MRI	GC/MS	0.001
NOR MLK	810223	MRI	GC/MS	0.001
OSLP#01	810219	MRI	GC/MS	0.001
P-14	810311	MRI	GC/MS	0.001
PRUD INS	810213	MRI	GC/MS	0.001
RICH#01	810224	MRI	GC/MS	0.001
S&KPROD#	731200	BARR	4AMINO	0.001

TABLE K5-7 (Continued)

PHENOLICS CONCENTRATION IN GROUND-WATER SAMPLES

WELL CODE	SAMPLE DATE	REPORT ID	METHOD	PHENOL PPM
S&KPROD#	740200	BARR	MBTH	0.007
S&KPROD#	760913	BARR	4AMINO	0.001
SITE-W23	810219	MRI	GC/MS	0.001
SLP#01	690900	HICKOK	X	0.014
SLP#01	730900	BARR	4AMINO	0.001
SLP#02	690900	HICKOK	X	0.008
SLP#03	680307	HICKOK	X	0.002
SLP#03	690900	HICKOK	X	0.012
SLP#03	730900	BARR	4AMINO	0.001
SLP#03	740200	BARR	MBTH	0.006
SLP#03	740900	BARR	MBTH	0.035
SLP#03	760401	BARR	4AMINO	0.001
SLP#03	760401	BARR	4AMINO	0.001
SLP#03	770526	BARR	4AMINO	0.002
SLP#03	770526	BARR	MBTH	0.001
SLP#03	770609	BARR	4AMINO	0.001
SLP#03	770609	BARR	4AMINO	0.001
SLP#03	770609	BARR	4AMINO	0.001
SLP#04	460114	HICKOK	X	0.100
SLP#04	460930	HICKOK	X	0.115
SLP#04	480623	HICKOK	X	0.005
SLP#04	480623	HICKOK	X	0.010
SLP#04	480630	HICKOK	X	0.005
SLP#04	480805	HICKOK	X	0.070

TABLE K5-7 (Continued)

PHENOLICS CONCENTRATION IN GROUND-WATER SAMPLES

WELL CODE	SAMPLE DATE	REPORT ID	METHOD	PHENOL PPM
SLP#04	480805	HICKOK	X	0.015
SLP#04	480813	HICKOK	X	0.070
SLP#04	680307	HICKOK	X	0.008
SLP#04	690900	HICKOK	X	0.014
SLP#04	810226	MRI	GC/MS	0.001
SLP#04	810312	MRI	GC/MS	0.001
SLP#04	810312	MRI	GC/MS	0.001
SLP#05	460930	HICKOK	X	0.020
SLP#05	471024	HICKOK	X	0.020
SLP#05	690900	HICKOK	X	0.014
SLP#05	810206	MRI	GC/MS	0.001
SLP#05	810213	MRI	GC/MS	0.001
SLP#05	810226	MRI	GC/MS	0.001
SLP#06	471016	HICKOK	X	0.007
SLP#06	480419	HICKOK	X	0.015
SLP#06	480423	HICKOK	X	0.015
SLP#06	680307	HICKOK	X	0.003
SLP#06	690900	HICKOK	X	0.023
SLP#06	810206	MRI	GC/MS	0.001
SLP#06	810213	MRI	GC/MS	0.002
SLP#06	810226	MRI	GC/MS	0.001
SLP#07	690900	HICKOK	X	0.013
SLP#08	690900	HICKOK	X	0.018
SLP#08	690900	HICKOK	X	0.012

TABLE K5-7 (Continued)

PHENOLICS CONCENTRATION IN GROUND-WATER SAMPLES

WELL CODE	SAMPLE DATE	REPORT ID	METHOD	PHENOL PPM
SLP#08	810226	MRI	GC/MS	0.001
SLP#09	690900	HICKOK	X	0.013
SLP#10	690900	HICKOK	X	0.014
SLP#10	730900	BARR	4AMINO	0.001
SLP#10	740200	BARR	MBTH	0.013
SLP#10	760401	BARR	4AMINO	0.001
SLP#10	770526	BARR	4AMINO	0.005
SLP#10	770526	BARR	MBTH	0.006
SLP#10	770609	BARR	4AMINO	0.001
SLP#10	770609	BARR	4AMINO	0.001
SLP#10	770609	BARR	4AMINO	0.001
SLP#10	810226	MRI	GC/MS	0.001
SLP#11	690900	HICKOK	X	0.010
SLP#11	810226	MRI	GC/MS	0.001
SLP#12	690900	HICKOK	X	0.018
SLP#12	690900	HICKOK	X	0.018
SLP#13	690900	HICKOK	X	0.018
SLP#13	690900	HICKOK	X	0.018
SLP#14	690900	HICKOK	X	0.009
SLP#15	810226	MRI	GC/MS	0.001
SLP#15	810312	MRI	GC/MS	0.001
STRAND	731200	BARR	4AMINO	1.000
STRAND	740200	BARR	MBTH	1.400
STRAND	760401	BARR	4AMINO	0.170

TABLE K5-7 (Continued)

PHENOLICS CONCENTRATION IN GROUND-WATER SAMPLES

WELL CODE	SAMPLE DATE	REPORT ID	METHOD	PHENOL PPM
STRAND	770526	BARR	4AMINO	0.140
STRAND	770526	BARR	?	0.390
WLWD N.	810227	MRI	GC/MS	0.001

TABLE K5-8

WELL CODE INDEX

Well Code	Well Name/Location	Well No.
SLP#03	SLP Municipal Well 3/29th & Jersey	W113
SLP#04	SLP Municipal Well 4/W.41 St. & Natchez	SLP4
SLP#05	SLP Municipal Well 5/Wyoming & 34th St.	SLP5
SLP#06	SLP Municipal Well 6/W.42nd & Zarthan	SLP6
SLP#07	SLP Municipal Well 7/2500 Lousiana	SLP7
SLP#08	SLP Municipal Well 8	SLP8
SLP#09	SLP Municipal Well 9/2500 Louisiana	SLP9
SLP#10	SLP Municipal Well 10/29th & Jersey	SLP10
SLP#11	SLP Municipal Well 11/29th & Jersey	SLP11
SLP#12	SLP Municipal Well 12/42nd & Zarthan	SLP12
SLP#13	SLP Municipal Well 13/Cedar Lake Road & Alabama	SLP13
SLP#14	SLP Municipal Well 14/Cedar Lake Road & Alabama	SLP14
SLP#15	SLP Municipal Well 15/29th & Jersey	SLP15
SLP#16	SLP Municipal Well 16	SLP16
EDINA#02	Edina Municipal Well 2	E2
EDINA#03	Edina Municipal Well 3	E3
EDINA#04	Edina Municipal Well 4	E4
EDINA#05	Edina Municipal Well 5	E5
EDINA#06	Edina Municipal Well 6	E6
EDINA#07	Edina Municipal Well 7	E7
EDINA#08	Edina Municipal Well 8	E8
EDINA#10	Edina Municipal Well 10	E10
EDINA#11	Edina Municipal Well 11	E11
EDINA#12	Edina Municipal Well 12	E12
EDINA#13	Edina Municipal Well 13	E13
EDINA#14	Edina Municipal Well 14	E14
EDINA#15	Edina Municipal Well 15	E15
EDINA#16	Edina Municipal Well 16	E16
EDINA#17	Edina Municipal Well 17	E17

TABLE K5-8 (cont'd)

Well Code	Well Name/Location	Well No.
EDINA#18	Edina Municipal Well 18	E18
HOPKN#1	Hopkins Municipal Well 1	H1
HOPKN#3	Hopkins Municipal Well 3	H3
HOPKN#4	Hopkins Municipal Well 4	H4
HOPKN#5	Hopkins Municipal Well 5	H5
HOPKN#6	Hopkins Municipal Well 6	H6
ACE MFG	Ace Mfg. (Strom Block)/3825 Edgewood	W065
ADM	ADM Well/St. Louis Park	-
ANDROC	Androc Chemical	W051
BECK PRO	Beck Products	-
CRIB-DIA	Crib Diaper Service, Sterilized Diaper Service	W034
DAY RG #2	Dayton Rogers #2	W037
DAY #3	Daytons #3	-
EIT HSP	Eitel Hospital	-
FLAME	Flame Industries	W029
HEDBRG #1	Hedberg, Friedheim & Co.	W106
HEDBRG #2	Hedberg, Friedheim & Co.	W114
MERIT	Merit Gauge (Suburban Sanitary Drainage)	W052
MINN RBR	Minnesota Rubber	W040
MON.W001	Monitor Well 1 - Barr/Hampshire	W001
MON.W002	Monitor Well 2 - Barr/33 St.	W002
MON.W006	Monitor Well 6 - Barr/Site	W006
MON.W010	Monitor Well 10 - Barr/Oxford St.	W010
MON.W011	Monitor Well 11 - Barr	W011
MON.W013	Monitor Well 13 - Barr/Lake St. & HWY #7	W013
MON.W016	Monitor Well 16 - Barr/Oxford St.	W016
MON.W017	Monitor Well 17 - Barr	W017
MON.W019	Monitor Well 19 - Barr	W019
MON. W003	Monitor Well 3-Barr/Site	W003
MON. W005	Monitor Well 5-Barr/Site	W005

TABLE K5-8 (cont'd)

Well Code	Well Name/Location	Well No.
MON. W007	Monitor Well 7-Barr	W007
MON. W008	Monitor Well 8-Barr	W008
MON. W009	Monitor Well 9-Barr/Lake St.	W009
MON. W012	Monitor Well 12-Barr	W012
MON. W014	Monitor Well 14-Barr/Lake St.	W014
MON. W015	Monitor Well 15-Barr/Site	W015
MON.W020	Monitor Well 20	W020
MON.W100	Monitor Well 100	W100
MON.W101	Monitor Well 101	W101
MON.W115	Monitor Well 115	W115
MON.W116	Monitor Well 116	W116
MON.W117	Monitor Well 117	W117
MON.W124	Monitor Well 124	-
MON.W133	Monitor Well 133	-
MIL RR	Milwaukee Railroad	W038
OSLP #01	Old St. Louis Park #1	W112
PARK PET	Park Pet Hospital	W075
PARK TH	Park Theater	W070
PRESTLT	Prestolite	W050
PROF INS	Professional Instruments	W076
PRUD INS	Prudential Insurance	W084
RED OWL	Red Owl	W080
SITE-W23	Site Well W23	W023
STRAND	Strand Mfg., Wayne Register, Midco Register, Robinson Rubber	W033
TERRY EX	Terry Excavating/3326 Republic Ave.	W027
TXTNK SC	Texatonka Shopping Center	W032
WEISMAN	Weisman Residence/2900 Cavelle	-
WELL 030	Private Well/3636 Quebec Ave.	W030
WELL 060	Private Well/3645 Rhode Island Ave.	W060
WLWD N.	Weldwood Nursing	W082

TABLE K5-8 (cont'd)

Well Code	Well Name/Location	Well No.
BRN GRN	Burdick Grain Co.	W035
HARTMAN	3700 Colorado	W41
HONWL #1	Honeywell #1	-
L. HARR #2	L. Harriet #2	-
METH HSP	Methodist Hospital	W48
MNNTK #11	Minnetonka Municipal Well 11	M11
MNNTK #12	Minnetonka Municipal Well 12	M12
MNNTK #13	Minnetonka Municipal Well 13	M13
MNNTK #14	Minnetonka Municipal Well 14	M14
NAT LED	National Lead	-
NHOSP #02	Northwest Hospital 2	-
NOR MLK	Norris Milk	-
P-14	Piezometer 14	P014
RICH #01	Richfield #1	-
S & K PROD	S & K Products	W045,W046

TABLE K5-9

GROUND-WATER DATA SOURCES

Report ID	Reference
Barr	"Soil and Ground Water Investigation, Coal Tar Distillation and Wood Preserving Site," St. Louis Park, MN. Barr Engineering. Phase I Report, May 1976. Phase II Report, June 1977.
Capsule	"GC/MS Analysis of Polynuclear Aromatic Hydrocarbons in Municipal Water Wells for the City of St. Louis Park." Capsule Laboratories. Reports submitted April 16, May 13, August 6, August 12 and August 30, 1982.
CH2M Hill	"Well Sampling and Analysis Program, Evaluation of Ground Water Treatment, St. Louis Park, MN" CH2M Hill Analytical Data Sheets and Chronological Summary of Water Quality Analyses.
EPA WHI	Memo from H. Taylor, WRD, to M. Hult, WRD, entitled "Reports and Statistics - Water Quality: Results of the St. Louis Park Water Samples." June 10, 1981.
Hickok	"Report on Drinking Water Treatment and Remedy Evaluation of St. Louis Park." Hickok. April 1981
MDH	Minnesota Department of Health Laboratory Data Sheets. Document Nos. 105008-105020, 6610438- 6610609.
MRC	Monsanto Research Corporation Data Sheets. See Appendix G.

TABLE K5-9 (cont'd)

Report ID	Reference
MRI	"Results of Analysis of Water Samples, Sludge Samples and Soil Samples for Polycylic Aromatic Compounds" Midwest Research Institute, EPA Contract 62-02-2814. October 7, 1981
SERCO	Reports of Laboratory Analysis to City of Hopkins. Reports dated 8/17/81, 9/23/81, 10/30/81 (2 same date), 12/21/81 and 1/29/82. Sanitary Engineering Laboratories, Inc.
USGS 79	"Preliminary Evaluation of Groundwater Contamination by Coal-Tar Derivatives" United States Geological Survey. January 1981.

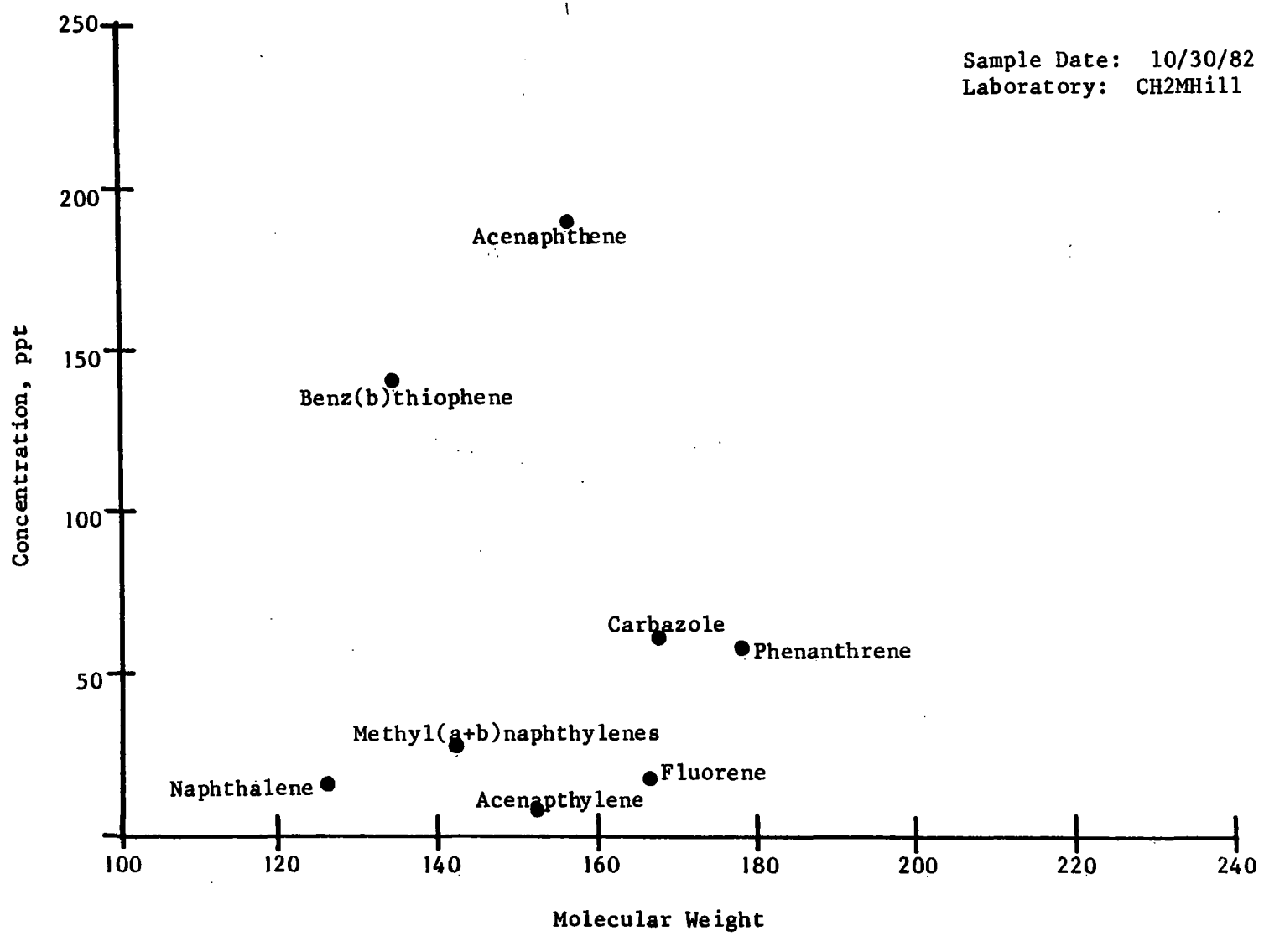


Figure K5-1 Molecular Weight Profile: SLP4

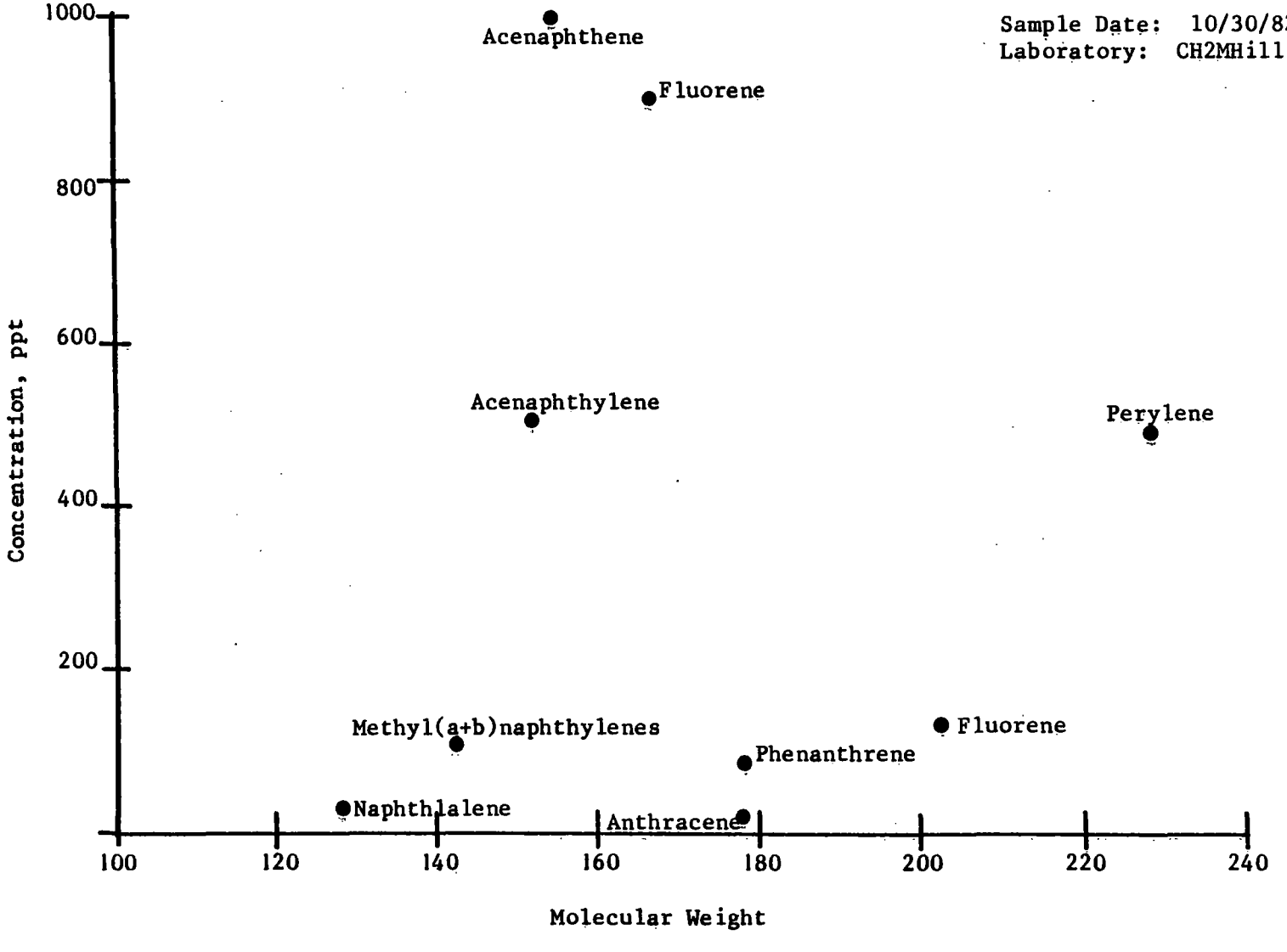


Figure K5-2 Molecular Weight Profile: SLP5

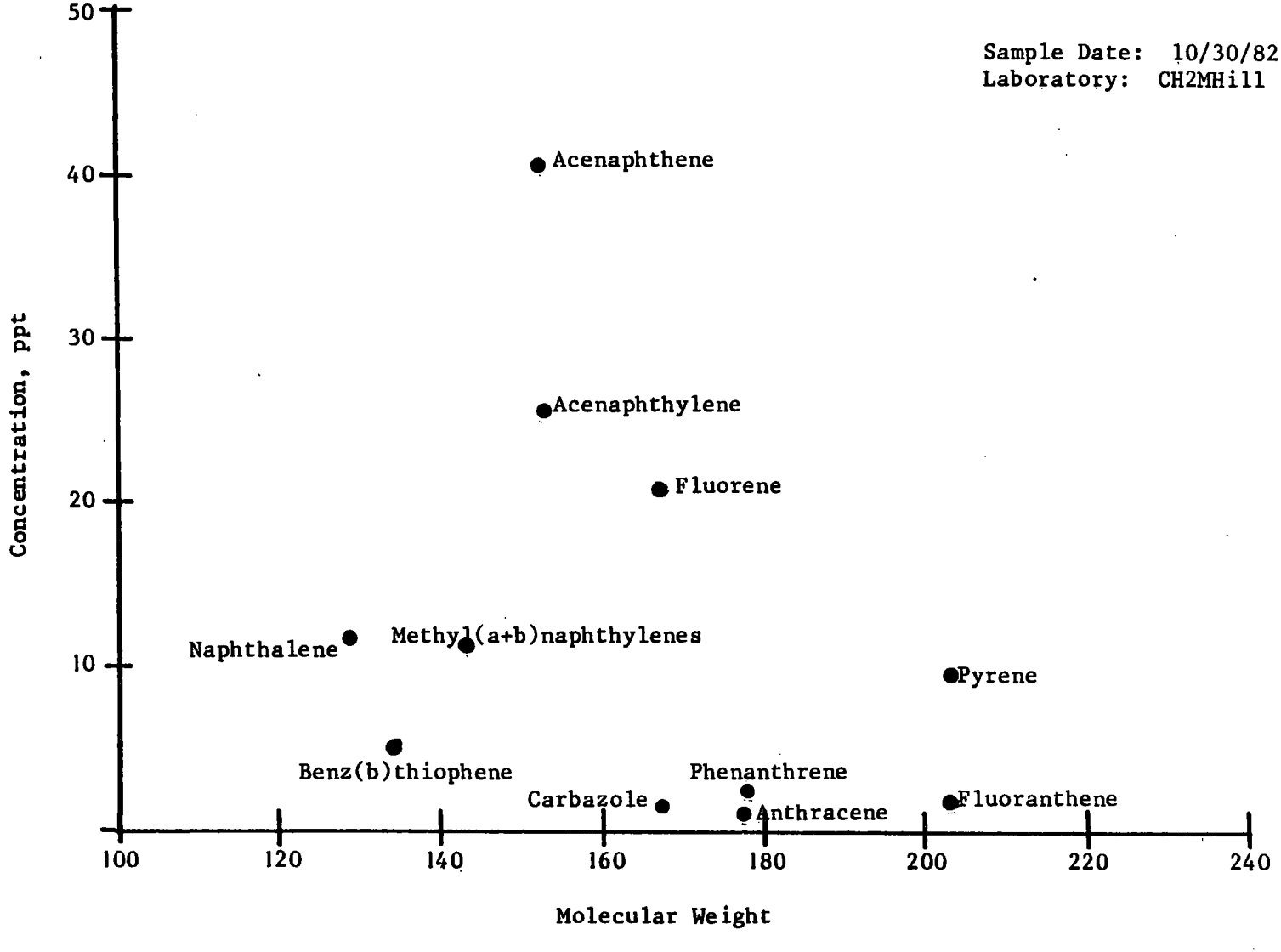


Figure K5-3 Molecular Weight Profile: SLP7

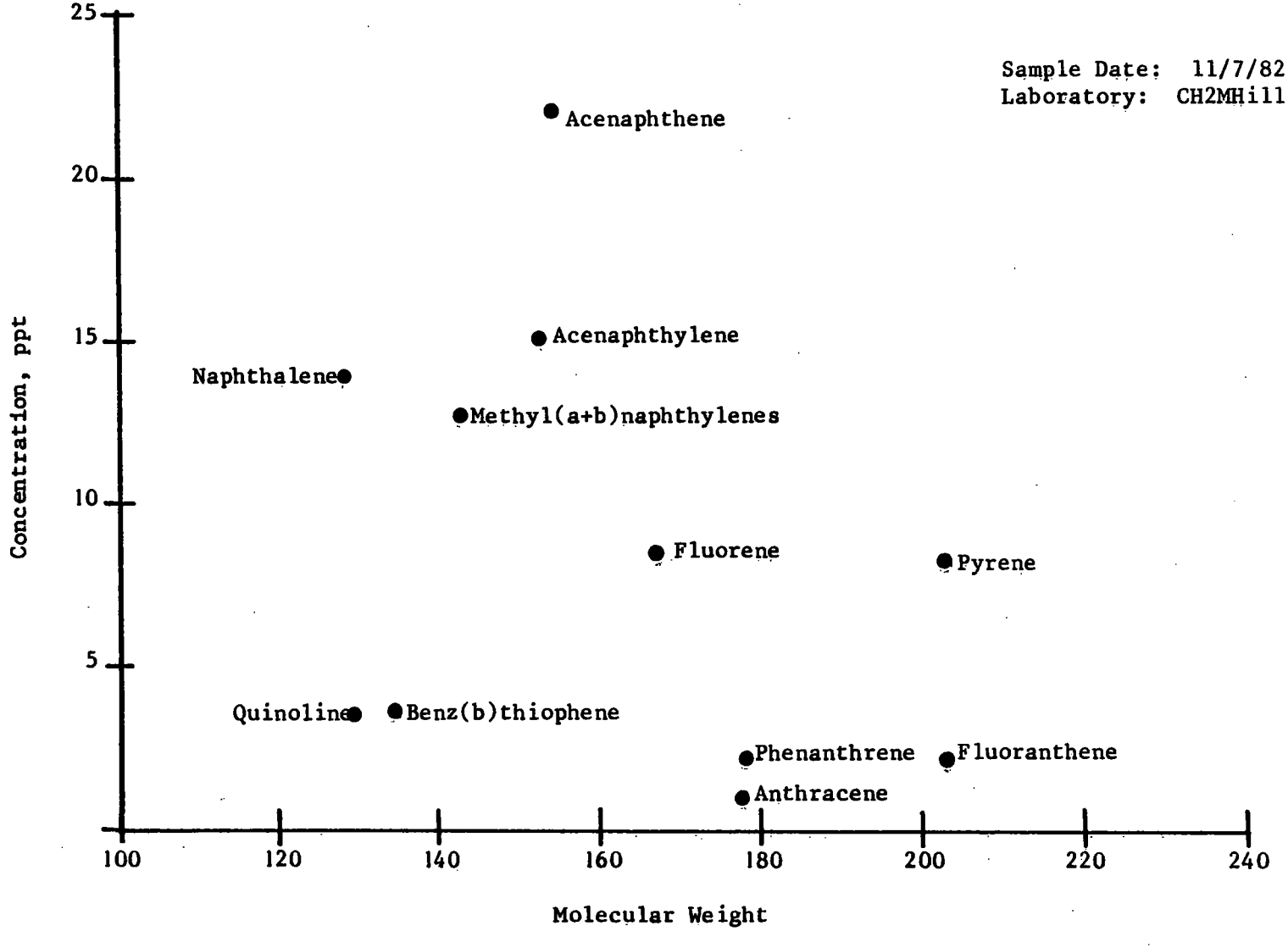


Figure K5-4. Molecular Weight Profile: SLP9

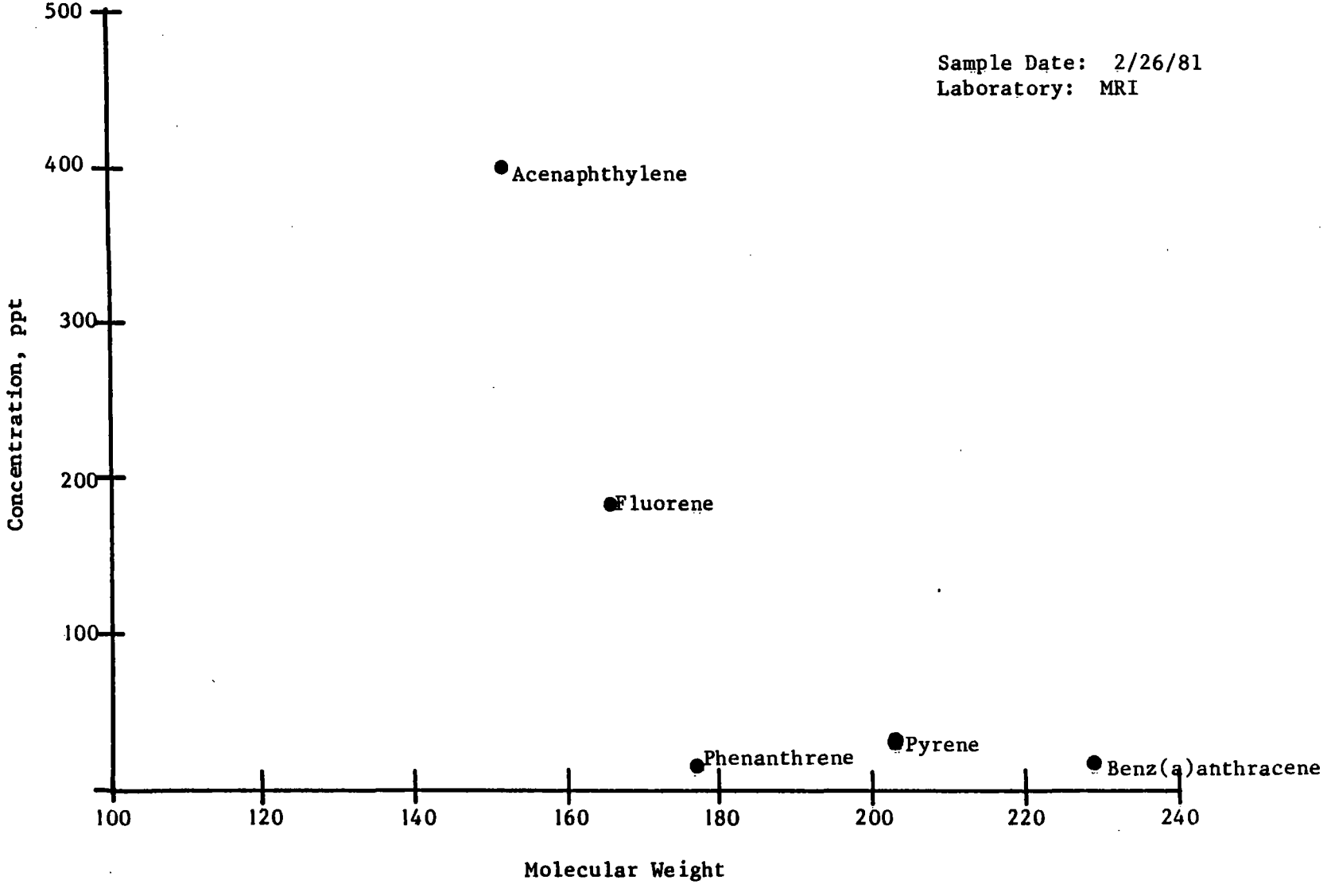


Figure K5-5 Molecular Weight Profile: SLP10

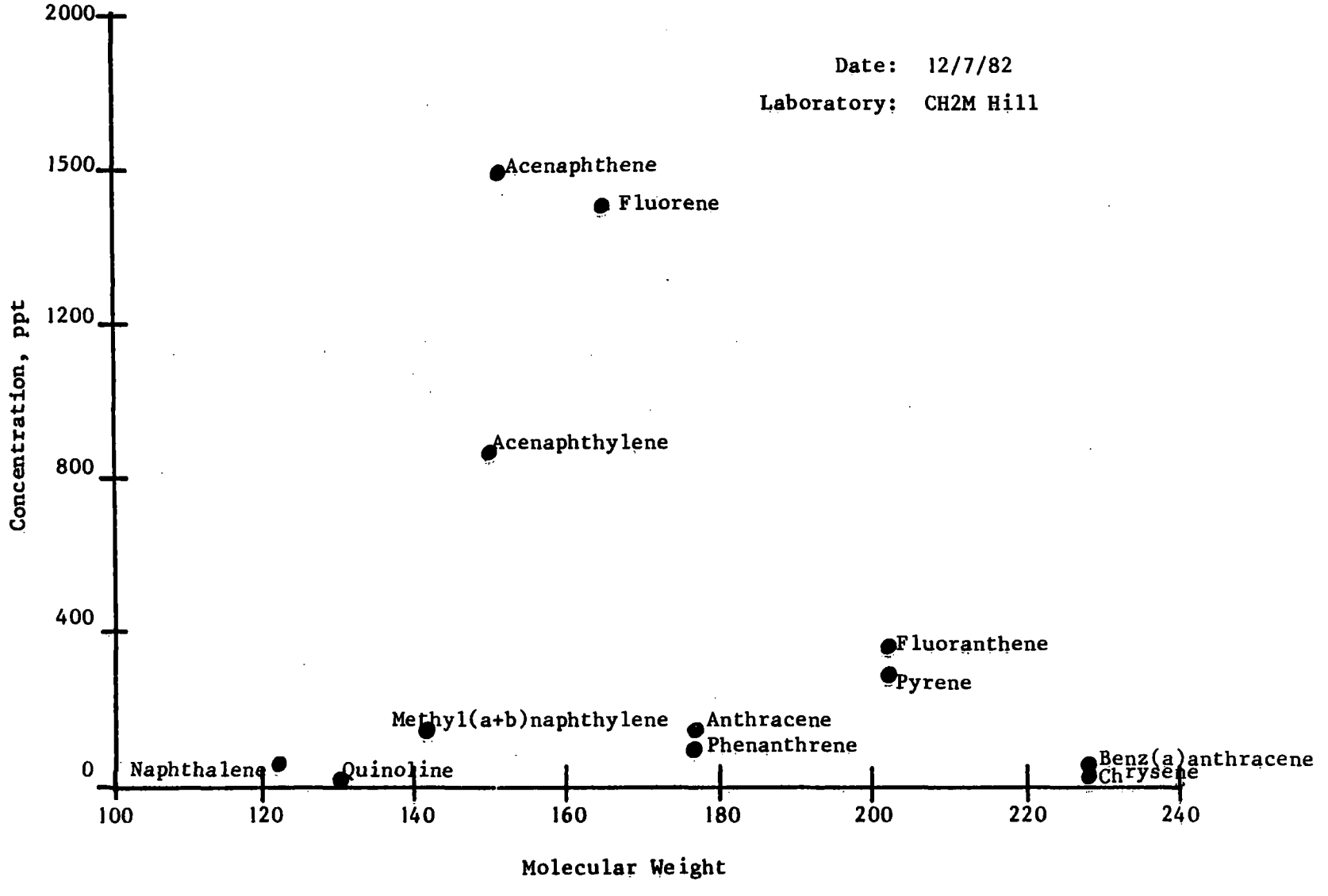


Figure K5-6 Molecular Weight Profile: SLP15

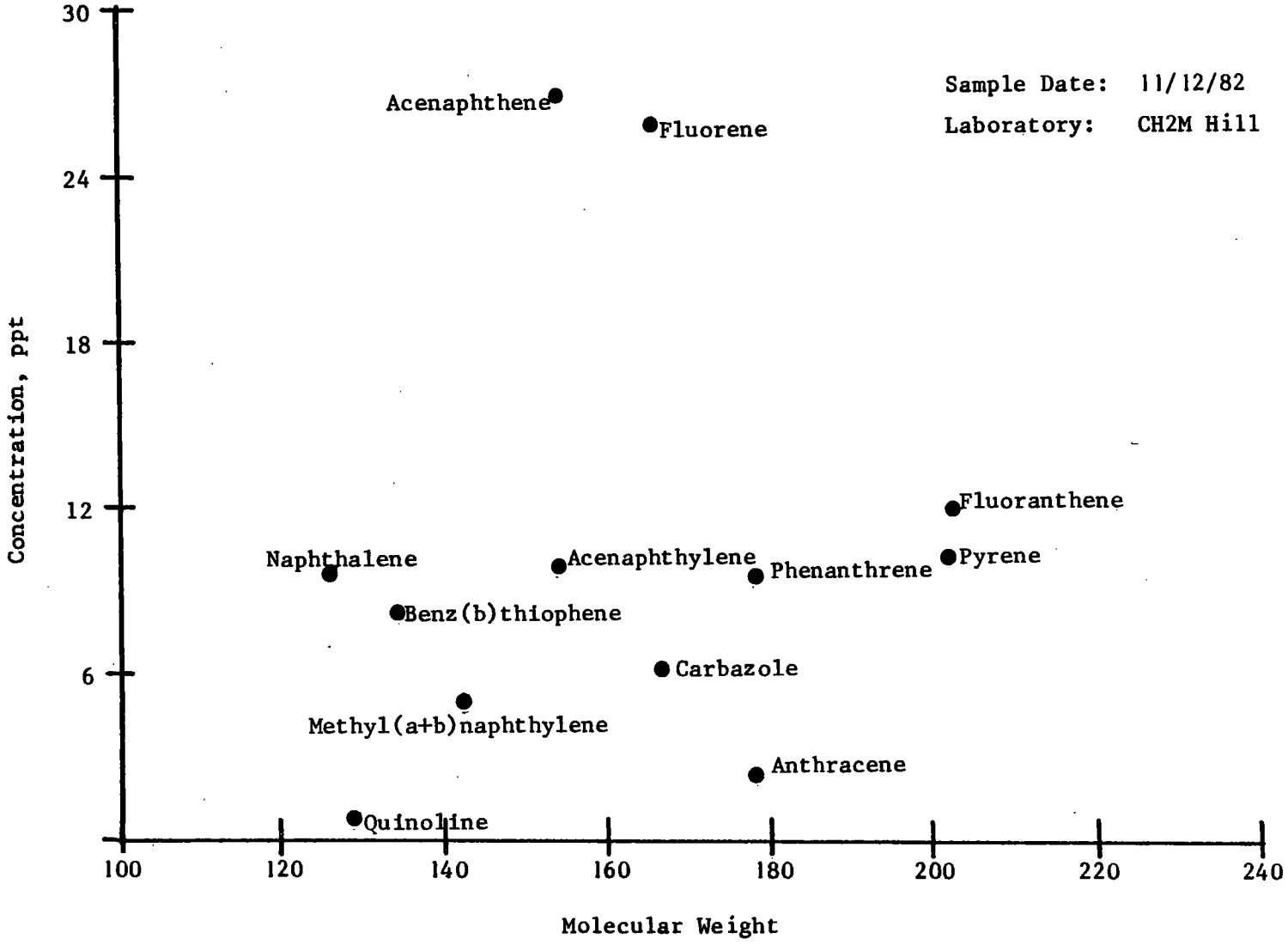


Figure K5-7 Molecular Weight Profile: Hopkins No. 3, H3

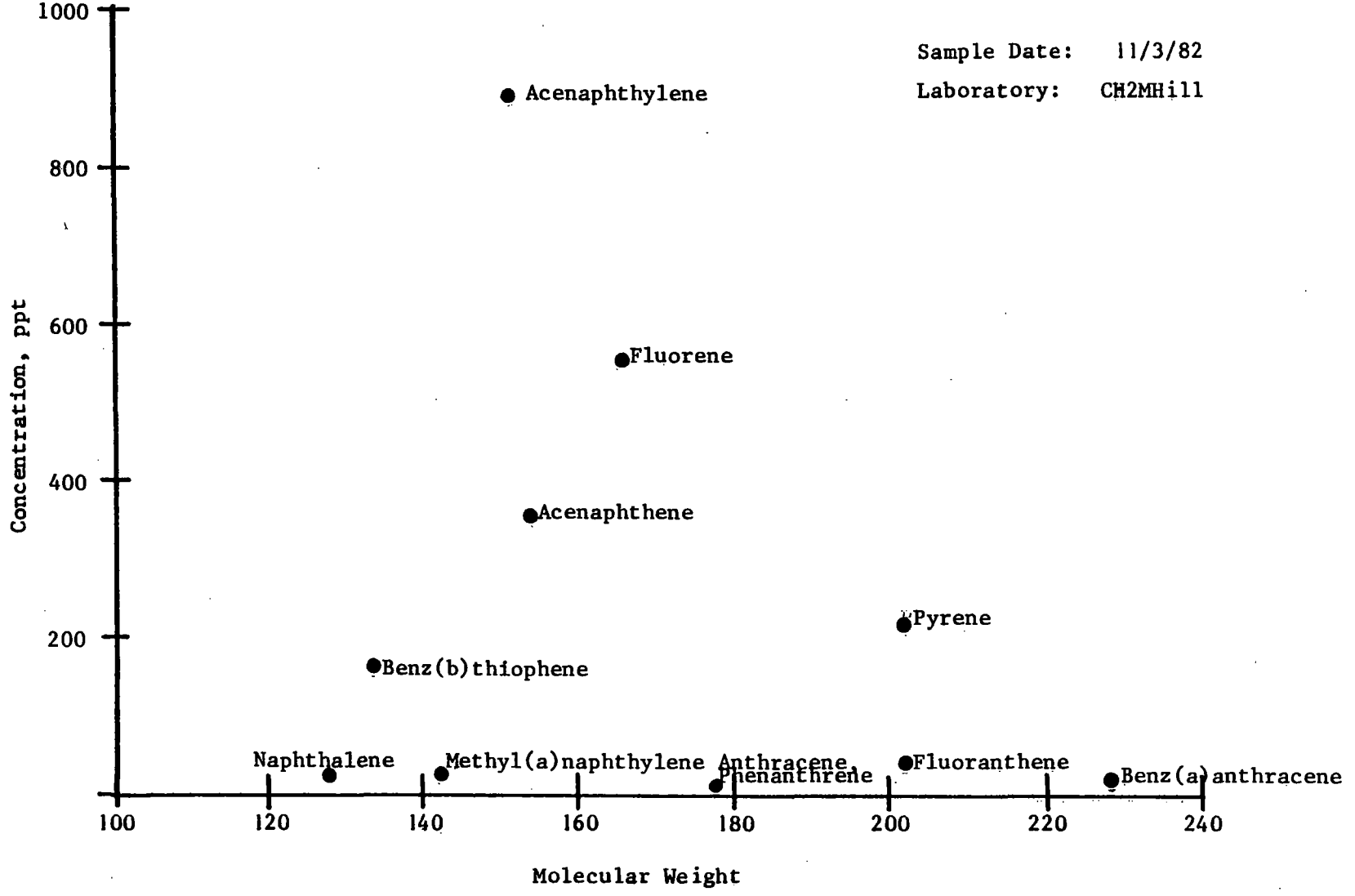


Figure K5-8 Molecular Weight Profile: Park Theater, W70

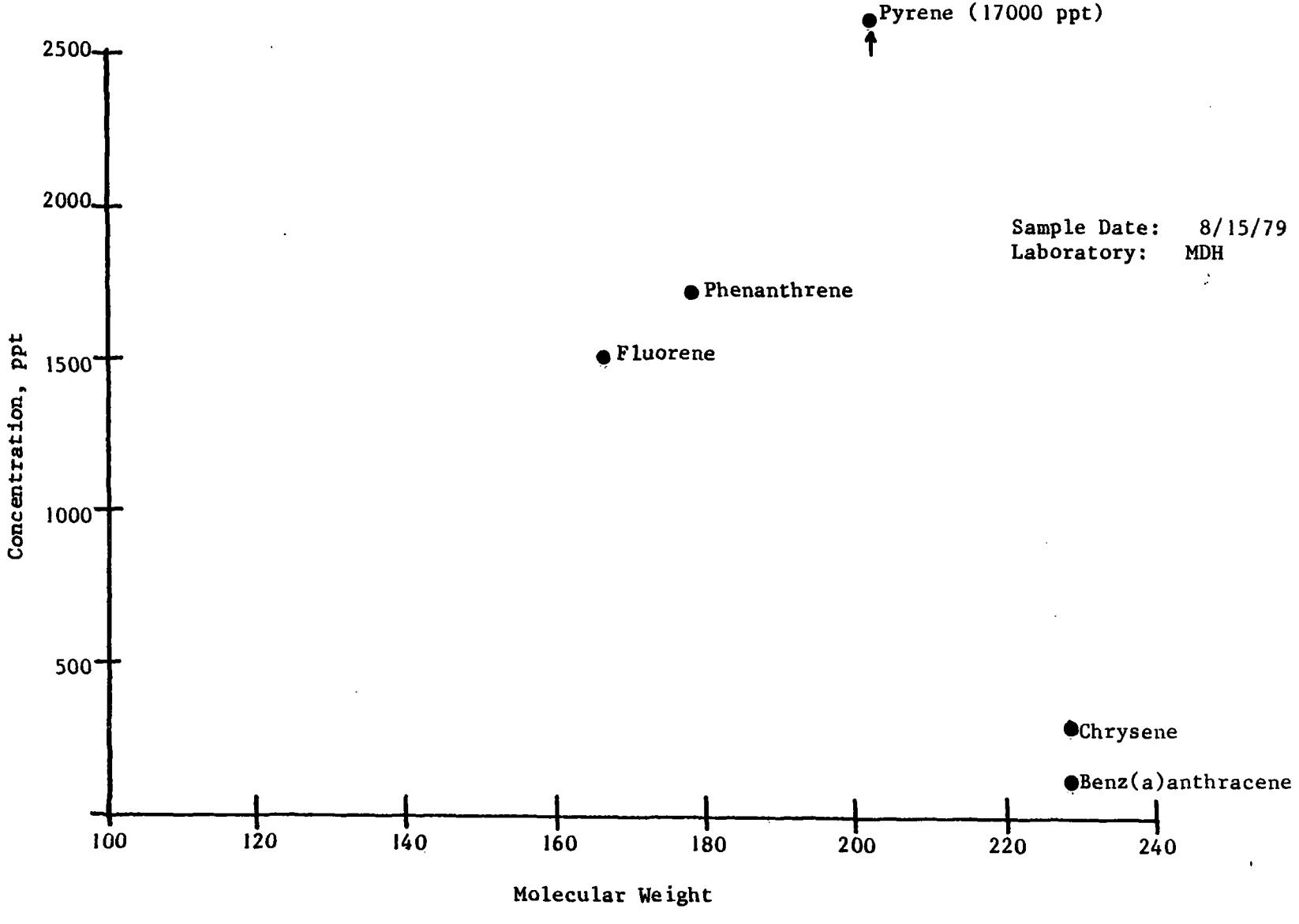


Figure K5-9 Molecular Weight Profile: Texatonka Shopping Center, W32

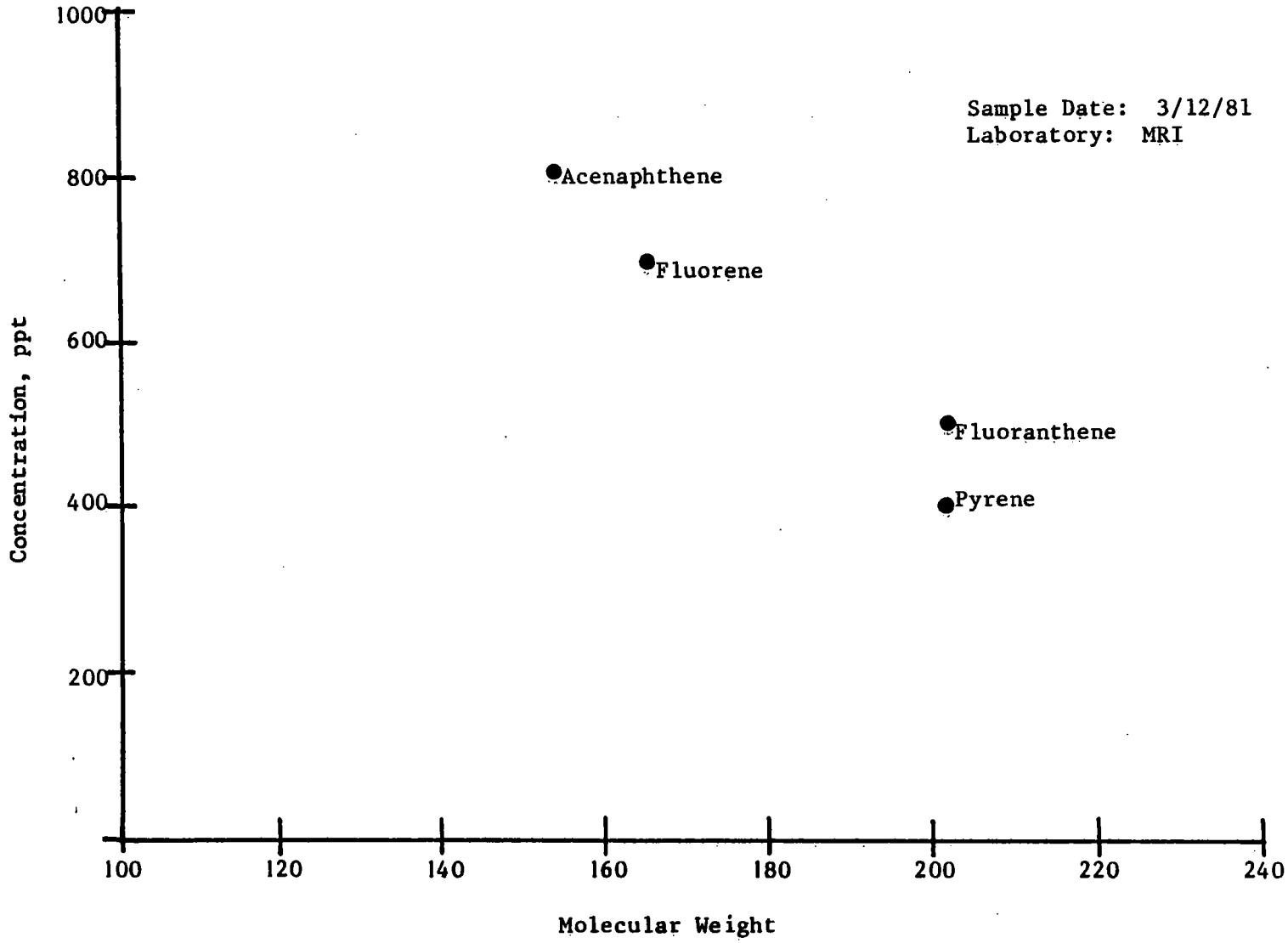


Figure K5-10 Molecular Weight Profile: Flame Industries, W29

APPENDIX L

PRESENT VALUE COST COMPARISONS

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LIST OF FIGURES

L1 INTRODUCTION

In order to compare the costs of various options, all costs must be expressed on a consistent basis. Consistent comparisons are commonly made by either expressing all future expenditures and annual costs in present value terms or by converting all costs to a uniform annual cost basis. In this study, the former method has been used for all cost comparisons. Taxes and, therefore, depreciation allowances have not been considered. The text "Cost and Optimization Engineering," by F.C. Jelen, has been the principal reference for the cost comparisons derived in this appendix.

L2 INFLATION AS A FACTOR IN TIME VALUE CONVERSION RELATIONSHIPS

In the United States, the Consumer Price Index (CPI) and the Producer Commodity Price Index (PPI) are two commonly used measures of the inflation rate. The annual percent change in the CPI reflects the change in the cost of living and considers housing, food and other personal costs. The PPI is an indicator of the price of commodities and includes metals, fuels, chemicals, machinery, etc.

Figure L2-1 traces the annual percent change in both the CPI and the PPI from 1952 to the present (Standard and Poors, 1982). During the 1950's and 1960's, when annual inflation rates were approximately 2 percent, it was not unreasonable to neglect inflation in time value conversion calculations. During the last decade, however, the inflation rate fluctuated widely and exceeded 10% for several years. Therefore, it is no longer appropriate to ignore inflation when evaluating costs.

When inflation is included in the conversion relationships, prices change every year. For example, if a constant annual inflation rate of d is assumed, an item that costs A now will cost $A(1+d)$ one year from now and $A(1+d)^2$ two years from now. The relationships for prices influenced by inflation is analogous to the time value conversion relationship between present worth and future worth:

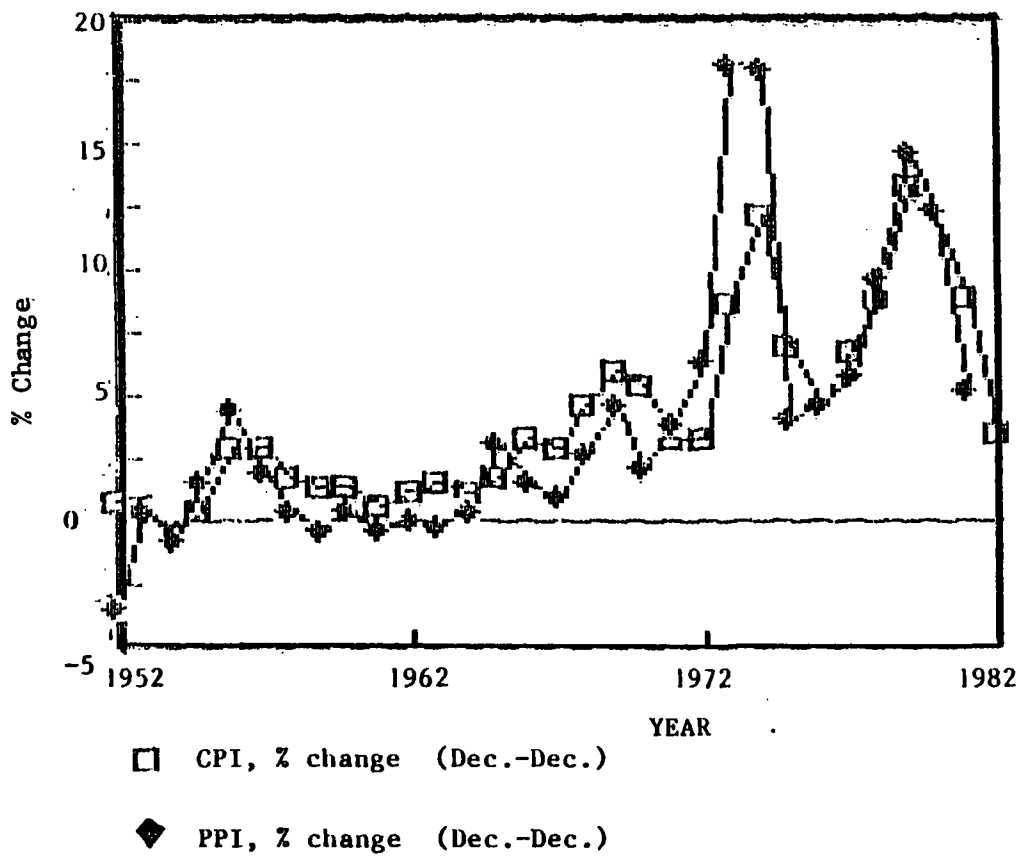

Figure L2-1 Historical Inflation Rates

$$A_0 = \frac{A}{(1+d)^n} \qquad \text{L-1}$$

A_0 = current price
A_n = price in n years
d = annual inflation rate

The present value of a future investment becomes:

$$P = \frac{S(1+d)^n}{(1+r)^n} \qquad \text{L-2}$$

S = the current cost of the item that that will be purchased in n years
r = annual rate of return

When inflation is considered, an annual end-of-year expense is no longer a uniform cost in actual dollars but a uniform annual burden, or unaburden. A unaburden may be considered to be a series of future expenses and may be expressed on a present value basis by the following equation.

$$P = R\left(\frac{1+d}{1+r} + \frac{(1+d)^2}{(1+r)^2} + \ldots + \frac{(1+d)^n}{(1+r)^n}\right) \qquad \text{L-3}$$

This equation is reduced to yield the final expression:

$$P = R\left(\frac{(1+d)(1+r)^n - (1+d)^{n+1}}{(r-d)\quad (1+r)^n}\right) \qquad \text{L-4}$$

When comparing cost options of unequal duration or when considering an option with a very long duration, it is useful to express costs on a capitalized cost basis. Capitalized cost is the present worth of the initial cost plus an infinite number of

replacements. Relationships to calculate both capitalized cost of an investment P_n with an expected life of n years and capitalized cost of a unaburden R are presented in Equations L-5 and L-6, respectively.

$$P_\infty = \frac{P_n\ (1+r)^n}{(1+r)^n - (1+d)^n} \qquad \text{L-5}$$

and

$$P_\infty = \frac{R(1+d)}{(r-d)} \qquad \text{L-6}$$

L3 EFFECTIVE RATE OF RETURN

Often inflation is not included explicitly, as in equations L-2 through L-6, but is reflected in the choice of a effective rate of return. The effective rate of return represents the net interest earned on an investment after the effects of inflation have been taken into account. Although the use of an effective rate of return is not rigorously correct, it introduces very little error into the time value calculations, as shown in Table L3-1. Therefore, all cost comparisons in this study have been made using an effective interest rate.

In predicting an effective rate of return, the level of risk involved in the investment is the determining factor. In their 1979 study, "Stocks, Bonds, Bills and Inflation: Historical Returns 1926-1978," Ibbotson and Sinquefield determined that relatively risk-free investments such as government bonds have historically yielded an effective rate of return of 0 to 2 percent. A diversified market portfolio of common stocks, on the other hand, has produced an effective annual return of approximately 6 percent. As a basis for comparison, this study has chosen a slightly more conservative rate of return of 5 percent.

The sensitivity of present value/future expenditure (P/S) and present value/annual cost (P/R) ratios to varying interest rates for

10, 20 and 100 years is shown in Figure L3-1. For costs of long duration, a change in rate of return of only 1 percent will have a significant impact on present value conversions. For example, at 100 years, a decrease in return from 5 percent to 4 percent results in a 25 percent increase in the ratio of present value to annual cost. To determine the sensitivity of various costs to changes in effective interest rates, present values in this study have been computed for interest rates of 4 percent and 6 percent as well as for the base case of 5 percent.

TABLE L3-1

COMPARISON OF PRESENT VALUE RATIOS:

INDEPENDENT INFLATION RATE VS. EFFECTIVE RATE OF RETURN

r	d	r_e	$P/R_{r,d}$	P/R_e	% Error	$P/S_{r,d}$	P/S_e	% Error
.05	.03	.02	8.67	8.98	3.57	.83	.82	1.2
.10	.03	.07	7.09	7.02	- .99	.52	.51	1.9
.08	.05	.03	8.6	8.53	- .8	.75	.74	1.3
.10	.05	.05	7.44	7.22	3.76	.63	.61	3.2
.05	.08	-.03	11.71	11.89	1.54	1.33	1.36	2.2
.10	.08	.02	9.06	8.98	- .88	.83	.82	1.9

Basis: n = 10 years

r = rate of return
d = inflation rate
r_e = effective rate of return = r-d

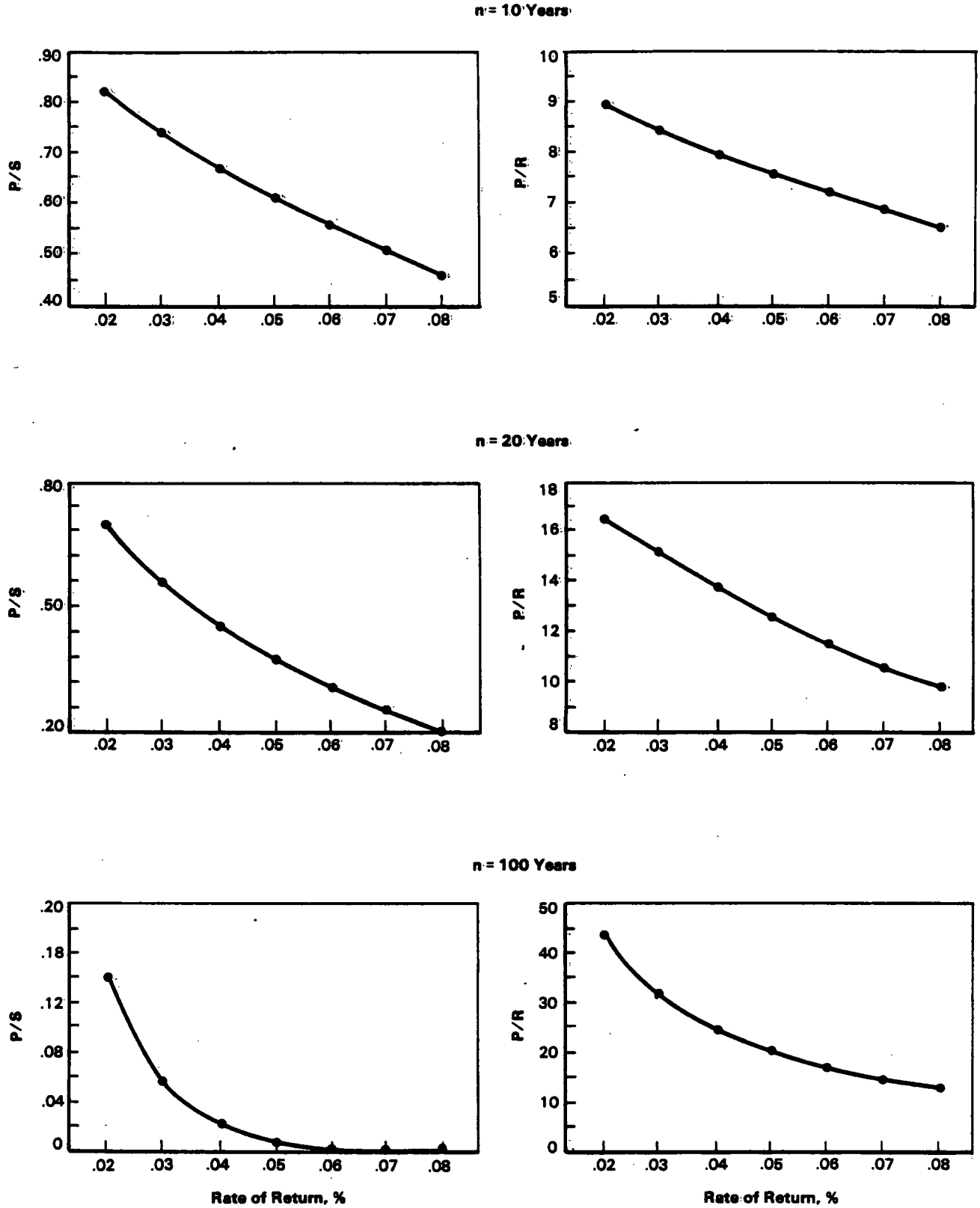

Figure L3-1 Sensitivity of Present Value Ratios to Changes in the Effective Interest Rate

L4 REFERENCES

Ibbotson and Sinquefield 1979. Stocks, Bonds, Bills and Inflation: Historical Returns 1926-1978.

Jelen, F. C. 1970. Cost and Optimization Engineering. New York: McGraw-Hill Book Company.

Standard and Poors Statistical Service 1982. Basic Statistics. Standard and Poors Corporation

Standard and Poors Statistical Service December 1982. Current Statistics. Standard and Poors Corporation.